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**Water-Supply Paper 426**

# SOUTHERN CALIFORNIA FLOODS OF JANUARY, 1916

BY

H. D. McGLASHAN AND F. C. EBERT

**Prepared in cooperation with the**
**STATE OF CALIFORNIA**

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# SOUTHERN CALIFORNIA FLOODS OF JANUARY, 1916.

By H. D. McGLASHAN and F. C. EBERT.

## INTRODUCTION.

The rains that swept southern California in mid-January, 1916, converted the streams into torrents that overran their banks and devastated wide areas of the most fertile land of the State. The rains were heaviest and the floods most disastrous in San Diego County, but they were also very heavy in parts of Riverside, San Bernardino, Los Angeles, and Ventura counties, and they wrought widespread ruin throughout the region that extends southward from Santa Clara River to the Mexican boundary, and westward from the north-south ranges of San Bernardino and San Diego counties to the ocean.

For nearly a month San Diego County was practically cut off from communication with the rest of the State. Fortunately the wireless could be used even after all telegraph and telephone lines failed, and supplies urgently needed at San Diego were brought in by steamer.

Aside from the loss of life, the most serious loss was that resulting from the destruction of the results of the work of generations on well-developed farm lands and their improvements. Dams that are broken down, bridges that are washed out, water mains, pipe lines, irrigation ditches, wells and pumps, and power plants that are damaged can be speedily repaired if funds are available, but it requires a long time to efface completely the track of a flood in a fertile, intensively cultivated river valley.

A record of the magnitude of such a flood and a study of the damage done and of the history of previous floods are of value not only in efforts to solve the general problem of flood prevention, but also in planning the complete utilization of the water resources of a region. In San Diego County, especially, where the losses were very heavy, a number of feasible reservoir sites have not been developed because the expense is apparently not yet warranted by the demand for their utilization for water supply alone. A detailed study may show, however, that the value of these sites as reservoirs for flood protection is sufficient to justify the county in assuming part of the cost of construction or assessing it against the properties to be protected. A fundamental requirement for this study is a knowledge of precipitation and stream flow, such as that presented in the records given in the following pages.

The records of precipitation have been collected by the United States Weather Bureau and many private parties at 156 stations fairly well distributed throughout the area. The records of stream flow have been collected by the United States Geological Survey and cooperating parties, and these also include many records furnished by private individuals. The importance of these records to engineers who are charged with the duty of designing and building structures along these streams is obvious and is impressively emphasized by the magnitude of the floods studied and the enormous destruction they have wrought.

The engineer will be impressed with the fact that whereas damages to property resulting from failure of engineering structures may be evaluated as a basis for determining the limit of economic cost of such structures, the loss of life can not be evaluated. Structures whose safety involves human life should, therefore, be designed much more securely than those whose failure would involve damage to property only.

## ACKNOWLEDGMENTS.

It is a distinct pleasure to acknowledge the cordial assistance rendered the writers by engineers, public officials, officers of various companies, and all others of whom such assistance was requested.

All stream-gaging work of the United States Geological Survey in California is done in cooperation with the State Department of Engineering, W. F. McClure, State engineer, and the State Water Commission, W. A. Johnstone (president), Irving Martin, and A. E. Chandler, commissioners.

The section of the report relating to flood run-off would have been much less complete and accurate if it had lacked the data and assistance furnished by Mr. W. S. Post, consulting engineer for the Volcan Land & Water Co. and the Cuyamaca Water Co. During the floods and in the weeks following these companies made a very strong effort to collect all information possible, and they also placed special parties in the field at different times to obtain such additional data as the writers desired to complete and check parts of the records. The chief engineer of the Sweetwater Water Co., Mr. John F. Covert, furnished a number of valuable flood records which he had carefully collected, and Messrs. G. S. Strout, E. R. Bowen, and C. H. Lee obtained stream measurements and furnished very helpful information regarding the floods on the San Luis Rey. The list would be long if mention were made of all parties who cooperated. Specific acknowledgment is made in connection with the detailed records.

All published and unpublished records of the United States Weather Bureau in the area covered by this report were furnished through Mr. G. H. Willson, section director, San Francisco. The local offices at Los Angeles and San Diego also furnished much detailed information. Records collected by private parties are acknowledged in connection with data for the stations. The Los Angeles County records were furnished by Mr. J. W. Regan, engineer of the flood-control district.

Estimates of the amount of damage to property were furnished as follows:

Assessors: Montgomery M. Moulton, San Diego County; James Sleeper, Orange County; C. B. Bayley, Riverside County; E. J. Gilbert, San Bernardino County; Ed W. Hopkins, Los Angeles County.

County engineers and surveyors: George Butler, San Diego County; J. L. McBride, Orange County; A. C. Fulmor, Riverside County; J. A. Sourwine, San Bernardino County; and F. H. Joyner, Los Angeles County, road commissioner.

City engineers: George Cromwell, San Diego; J. M. Oakey, San Bernardino; Clarence E. Bayley, Pomona; R. V. Orbison, Pasadena; Homer Hamlin, Los Angeles; Albert de Ruiz, Long Beach; and Chas. E. Chambers, president board of trustees, San Jacinto.

Railway engineers: A. Ervast, chief engineer, San Diego & South Eastern Railway Co., San Diego Electric Railway Co.; E. J. Kallright, general superintendent, San Diego & Arizona Railway Co.; W. J. Gough, superintendent, Los Angeles & San Diego Beach Railway Co.; J. McMillan, general manager, Pacific Electric Railway Co.; Arthur Maguire, chief engineer, San Pedro, Los Angeles & Salt Lake Railroad Co.; J. Q. Barlow, assistant chief engineer, Southern Pacific Co.; R. B. Ball, engineer Grand Division, Atcheson, Topeka and Santa Fe Railway Co.

Water company engineers: John F. Covert, chief engineer, Sweetwater Water Co.; F. M. Faude, assistant manager, Cuyamaca Water Co.; J. B. Dixon, superintendent, Escondido Mutual Water Co.; Francis Cuttle, president, Riverside Water Co.; W. S. Post, consulting engineer, Lake Hemet Water Co.; H. R. Case, manager, Temescal Water Co.

Miscellaneous: F. H. Tolle, secretary and general manager, South Coast Land Co.; R. C. Starr, hydraulic engineer, Pacific Light & Power Corporation; H. W. Dennis, construction engineer, Southern California Edison Co.; C. O. Poole, chief engineer, Southern Sierras Power Co.; Austin B. Fletcher, State highway engineer; J. L. Ord, division plant superintendent, Western Union Telegraph Co.; C. L. Lewis, superintendent, Postal Telegraph-Cable Co.; D. P. Fullerton, general superintendent of plant, Pacific Telephone and Telegraph Co.; L. M. Klauber, superintendent electric department, San Diego Consolidated Gas & Electric Co.; L. M. Drown, manager, Western Salt Co.; T. L. Barnes, general manager, Fenton-Sumption-Barnes Co.; C. R. Olberg, U. S. Indian Office; Maj. G. B. Pillsbury, Corps of Engineers, U. S. Army.

The loss of life was reported by the following coroners: Dr. Otto G. Marsh, San Diego County; Theo. A. Winbigler, Orange County; C. S. Dickson, M. D., Riverside County; J. L. McMinn, San Bernardino County; and the coroner's office of Los Angeles County.

## PRECIPITATION.

### STORMS OF JANUARY, 1916.

The storms from which the floods of January, 1916, resulted began January 17, but light rains had been reported for several days preceding. The United States Weather Bureau[1] described the storms as follows:

> It seems reasonable to suppose that the storm which swept over Hawaii on the 18th–19th passed inland over California on the 27th. It is charted as Low No. XIV, Chart III. About a week previous Low No. X, Chart III, passed inland over the middle California coast on the 17th, crossed the south-central part of the State on the 18th, and then moved northeastward into Wyoming by the morning of the 19th. During its movement over the south-central portion of California the storm slackened its progressive movement, meanwhile giving very heavy rains over the counties of southern California. Light rains had fallen during the previous three or four days and conditions were unusually favorable for a high run-off in connection with the heavy rains of the 17th and 18th. * * * The resulting floods were severe and much damage was done to railroads, bridges, highways, land under cultivation, and to the harbor of Los Angeles, by reason of the mass of silt deposited thereon.
>
> A second deluge of rain descended upon the counties of southern California in connection with Low No. XIV, mentioned in a preceding paragraph. The second storm was of much shorter duration. At San Diego, Cal., the rain began at 7.18 p. m. of the 26th and ended at 7.45 p. m. on the 27th. The total fall amounted to 2.41 inches. This rainstorm was attended by unusually high winds for southern California, the average velocity at San Diego being about 30 miles per hour, with a maximum of 54 miles from the south at 4.29 a. m. of the 27th. The reservoirs in the county whence the water supply of the city of San Diego is drawn were already nearly full as a result of the rains of the previous week, and all of them, evidently, were not in a condition to withstand the added strain put upon them by the rains of the 26th–27th.

The table on pages 12–16 contains records of precipitation not only at stations maintained by the Weather Bureau, but at many other stations maintained publicly or privately in the basins described in this paper. A few records obtained in adjoining river basins have been added for purposes of comparison and indicate the limits of excessive precipitation during the two storms. (See Pl. I, in pocket.)

From the records presented in these tables the mean precipitation for the principal drainage basins in San Diego County has been computed for the period covered by the storms. Records for these basins were collected at 63 stations fairly well distributed throughout the region. The stations were plotted on the map (Pl. I), and lines of equal precipitation were drawn. The boundary of each drainage basin above selected points was also indicated, and the areas between adjacent precipitation lines within each basin were measured with a planimeter. The results are given in the following table:

---

[1] Monthly Weather Review, vol. 44, No. 1, January, 1916.

*Mean precipitation in drainage basins in San Diego County, Cal., for period Jan. 14 to 30, 1916.*

| Station. | Drainage area. | Mean precipitation. |
|---|---|---|
| | *Square miles.* | *Inches.* |
| Otay River at Lower Otay dam | 98.6 | 19.2 |
| Jamul Creek above Lower Otay reservoir | 69.8 | 21.0 |
| Sweetwater River at Descanso | 43.7 | 27.4 |
| Sweetwater River at Sweetwater dam | 181 | 21.8 |
| San Diego River at diverting dam | 102 | 27.6 |
| San Diego River at Lakeside | 203 | 25.0 |
| San Diego River at Mission dam | 375 | 21.4 |
| San Diego River at San Diego | 434 | 19.9 |
| San Vicente Creek | 74.9 | 19.2 |
| Santa Ysabel Creek near Mesa Grande | 53.4 | 30.3 |
| Santa Ysabel Creek near Ramona | 110 | 26.8 |
| San Dieguito River at Carroll dam site | 299 | 23.6 |
| San Dieguito River at mouth | [a] 340 | 22.4 |
| Santa Maria Creek near Ramona | 57.3 | 21.2 |
| San Luis Rey River near Mesa Grande | 209 | 24.9 |
| San Luis Rey River near Nellie | 240 | 25.4 |
| San Luis Rey River near Pala | 322 | 25.7 |
| San Luis Rey River at Bonsall | 465 | 24.3 |
| San Luis Rey River at Oceanside | 565 | 22.6 |

[a] Approximate.

In the mountainous part of the area much of the precipitation was in the form of snow, as shown by the following table, in which the amount of snow on the ground on January 15 is compared with that remaining January 31:

*Snowfall, in inches, in mountains of southern California for January, 1916.*[a]

| Station. | Total snowfall. | Amount on ground on 15th. | Amount on ground on 31st. | Compared with normal. |
|---|---|---|---|---|
| Bear Valley dam | 36 | 4 | 30 | + 9 |
| Converse Nursery | 46 | 3 | 6 | ........ |
| Holcomb | 80 | 22 | 36 | +59 |
| Squirrel Inn | 41 | 20 | 27 | +32 |
| Seven Oaks | 36 | ........ | ........ | +22 |
| Nellie | 21 | 0 | 6 | ........ |
| Julian | 15 | 7 | 1 | ........ |

[a] Willson, G. H., Climatological data, California section, January, 1916, p. 11.

*Precipitation, in inches, at stations in southern California, for January, 1916.*

| Station. | No. on Pl. I. | Elevation (feet). | Day of month. | | | | | | | | | | | | | | | | | Total for period. | Total for month. | Authority. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| **Tia Juana basin:** | | | | | | | | | | | | | | | | | | | | | | |
| Barrett dam | 101 | 1,600 | 1.21 | 2.30 | 0.64 | 4.45 | 3.30 | 1.04 | 0.88 | ..... | ..... | ..... | ..... | 0.16 | 0.38 | 1.60 | 4.75 | 0.05 | 0.60 | 21.36 | 21.91 | San Diego. |
| Campo | 102 | 2,543 | 2.35 | 1.17 | 4.75 | 2.23 | 1.20 | 1.23 | ..... | ..... | ..... | ..... | ..... | ..... | .55 | 1.83 | 4.35 | .10 | .38 | 20.14 | 20.44 | U. S. Weather Bureau. |
| Morena reservoir | 103 | 3,010 | ..... | 3.10 | .98 | 5.13 | 4.65 | 1.62 | 1.33 | .05 | ..... | ..... | 0.02 | .21 | .40 | 1.97 | 6.13 | .10 | .54 | 26.23 | 28.09 | San Diego. |
| **Otay basin:** | | | | | | | | | | | | | | | | | | | | | | |
| Dulzura summit | 104 | 1,300 | 1.94 | .67 | 3.22 | 4.58 | .88 | 1.01 | ..... | ..... | ..... | ..... | .09 | .34 | 2.20 | 9.90 | | .62 | ..... | 25.45 | 26.75 | Do. |
| Jamul ranch | 105 | 800 | ..... | 3.65 | 3.80 | 2.35 | .61 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 6.65 | | 1.48 | ..... | 18.54 | 20.53 | Do. |
| Jamul store | 106 | 1,050 | .74 | .74 | 3.00 | 3.60 | ..... | .86 | ..... | ..... | ..... | ..... | ..... | .75 | 2.00 | 3.86 | | 1.18 | ..... | 16.73 | 17.76 | Do. |
| Lower Otay reservoir | 107 | 490 | ..... | .48 | .46 | 1.86 | 1.82 | .53 | .45 | ..... | ..... | ..... | ..... | .02 | .15 | 1.12 | 2.25 | | .25 | 9.39 | 9.91 | U. S. Weather Bureau. |
| **Sweetwater basin:** | | | | | | | | | | | | | | | | | | | | | | |
| Alpine Heights | 108 | 1,800 | 1.56 | .78 | 4.76 | 3.27 | 1.29 | .50 | ..... | ..... | ..... | ..... | ..... | .63 | 2.75 | 5.45 | .12 | .50 | ..... | 21.61 | 22.90 | J. F. Covert. |
| Bonita | 109 | 110 | .65 | Tr. | .50 | 1.48 | 2.16 | .58 | .41 | ..... | ..... | ..... | ..... | .04 | .14 | 1.26 | 2.10 | .43 | ..... | 9.75 | 10.29 | U. S. Weather Bureau. |
| Descanso | 110 | 3,350 | ..... | 2.09 | 1.00 | 6.50 | 4.80 | 1.65 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 11.00 | | ..... | ..... | 27.04 | 29.42 | C. H. Ellis. |
| Descanso ranger station | 111 | 3,500 | ..... | 2.12 | 1.02 | 6.36 | 4.98 | 1.33 | .67 | ..... | ..... | ..... | .02 | .38 | .73 | 3.11 | 7.07 | .09 | .80 | 28.68 | 30.67 | U. S. Forest Service. |
| Green Valley | 112 | 4,100 | 2.30 | .05 | 2.96 | 6.17 | 2.91 | .85 | ..... | ..... | ..... | ..... | ..... | 1.46 | .22 | 6.48 | 2.04 | .38 | .51 | 26.33 | 28.13 | J. F. Covert. |
| Sweetwater dam | 113 | 300 | .45 | .11 | 1.10 | 1.10 | 1.51 | .46 | .38 | ..... | ..... | ..... | ..... | .07 | .15 | 2.87 | | ..... | .35 | 8.55 | 8.97 | Do. |
| **San Diego basin:** | | | | | | | | | | | | | | | | | | | | | | |
| Boulder Creek | 114 | 2,700 | 1.10 | .48 | 4.20 | 3.10 | 2.85 | 3.75 | .60 | .56 | ..... | ..... | ..... | .30 | .68 | 4.70 | 3.36 | .60 | ..... | 26.28 | 31.51 | Cuyamaca Water Co. |
| Chocolate | 115 | 750 | .45 | 1.22 | .71 | 4.13 | 2.87 | 1.35 | .65 | ..... | ..... | ..... | ..... | .06 | .45 | 1.22 | 5.19 | ..... | .34 | 18.64 | 19.81 | Do. |
| Cuyamaca, East | 116 | 4,680 | | | | | 13.28 | | | | | | | | 10.30 | | | | ..... | 23.58 | 26.85 | Do. |
| Cuyamaca reservoir | 117 | 4,677 | 1.20 | .72 | 3.35 | 5.83 | 5.27 | 1.59 | ..... | ..... | ..... | .03 | .23 | 1.63 | 1.53 | 8.54 | 1.30 | 1.12 | ..... | 32.34 | 36.50 | U. S. Weather Bureau. |
| Diverting dam | 118 | 820 | .60 | 1.11 | .69 | 3.80 | 3.30 | .53 | .53 | ..... | ..... | ..... | ..... | .23 | .27 | 1.64 | 5.20 | .10 | .27 | 18.14 | 19.25 | Cuyamaca Water Co. |
| El Cajon | 119 | 482 | .52 | .46 | 1.86 | 4.41 | 1.24 | .60 | ..... | ..... | ..... | ..... | ..... | .26 | .05 | 5.60 | .74 | .10 | .25 | 16.09 | 16.68 | U. S. Weather Bureau. |
| El Cajon, Sweetwater Pass | 120 | 670 | .41 | .60 | .66 | 3.11 | 3.31 | .60 | .49 | ..... | ..... | ..... | ..... | .08 | .23 | .19 | 4.00 | ..... | .24 | 15.71 | 16.49 | Cuyamaca Water Co. |
| Grossmont | 121 | 650 | ..... | .70 | .64 | 2.50 | .76 | ..... | ..... | ..... | ..... | ..... | ..... | .12 | .32 | 1.94 | 3.48 | ..... | ..... | 10.46 | 11.24 | Do. |
| Julian | 122 | 4,220 | Tr. | 1.58 | .95 | 5.95 | 6.49 | 1.73 | 1.36 | ..... | ..... | ..... | .06 | .19 | 1.31 | 3.31 | 7.68 | .85 | .58 | 31.54 | 35.85 | U. S. Weather Bureau. |
| Lakeside | 123 | 410 | .85 | | | 7.36 | | | ..... | ..... | ..... | ..... | ..... | .20 | | 5.30 | | .18 | ..... | 13.89 | 14.42 | J. H. Beadle. |
| La Mesa reservoir | 124 | 510 | ..... | .65 | .55 | 2.36 | .56 | ..... | ..... | ..... | ..... | ..... | ..... | .12 | ..... | 1.56 | 3.32 | .04 | .33 | 9.49 | 10.13 | Cuyamaca Water Co. |
| Los Coches | 125 | 700 | ..... | 1.14 | .84 | 2.52 | 2.45 | .55 | .60 | ..... | ..... | ..... | ..... | .09 | .33 | 1.05 | 3.15 | .18 | ..... | 12.90 | 13.56 | Do. |
| Miramar ranch | 126 | 600 | .50 | .20 | .45 | 3.75 | 1.75 | 1.45 | ..... | ..... | ..... | ..... | ..... | .55 | .35 | 5.20 | .70 | ..... | .30 | 15.20 | 16.20 | Miramar ranch. |
| Pine Hills | 127 | 4,900 | 1.09 | .80 | 3.39 | 7.08 | 4.10 | 1.45 | ..... | ..... | ..... | ..... | .13 | .94 | .64 | 7.80 | 1.60 | .25 | .60 | 29.87 | 33.74 | Cuyamaca Water Co. |
| Point Loma | 128 | 302 | .08 | .62 | .37 | .80 | 2.10 | .93 | .70 | ..... | ..... | ..... | .01 | .15 | .14 | 2.14 | 1.27 | .08 | .23 | 9.57 | 10.09 | U. S. Weather Bureau. |
| San Diego | 129 | 87 | .53 | .09 | .95 | 1.55 | .31 | .80 | ..... | ..... | ..... | ..... | Tr. | .21 | .22 | 2.19 | .06 | .17 | ..... | 7.08 | 7.56 | Do. |
| Shillings ranch | 130 | 4,600 | ..... | | | | | | 17.50 | | | | | | | | 19.00 | | | 36.50 | 40.01 | Cuyamaca Water Co. |
| **San Dieguito basin:** | | | | | | | | | | | | | | | | | | | | | | |
| Carroll dam site | 131 | 270 | .17 | .33 | .41 | 2.83 | 2.57 | .71 | .28 | ..... | ..... | .01 | ..... | .49 | .38 | 5.07 | | ..... | .32 | 13.57 | 14.94 | Volcan Land & Water Co. |
| Escondido | 132 | 657 | .52 | .36 | 2.00 | 4.85 | 1.95 | 1.06 | ..... | ..... | ..... | ..... | ..... | .71 | .08 | 5.53 | .58 | .50 | .11 | 18.25 | 19.55 | U. S. Weather Bureau. |
| Mesa Grande (Angel) | 133 | 3,900 | | | 20.00 | | | ..... | ..... | ..... | ..... | | | | 11.00 | | | | ..... | 31.00 | 33.60 | Volcan Land & Water Co. |
| Mesa Grande (Davis) | 134 | 3,430 | .87 | .60 | 3.26 | 8.08 | 3.99 | .10 | ..... | ..... | ..... | ..... | .17 | 1.19 | .34 | 8.55 | 1.63 | .33 | .65 | 29.76 | 33.28 | U. S. Weather Bureau. |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pamo dam site | 135 | 820 | .... | .91 | .63 | 5.55 | 3.40 | 1.55 | .71 | .... | .... | .... | .... | .35 | .36 | 1.81 | 6.10 | 1.05 | .40 | 22.82 | 24.47 | Volcan Land & Water Co. |
| Ramona (Sentinel) | 136 | 1,440 | .43 | .40 | 1.90 | 4.90 | 1.55 | 1.40 | .... | .... | .... | .... | .... | .30 | 2.45 | 5.15 | 1.30 | .... | .... | 19.78 | 21.59 | Do. |
| Rose Glen | 137 | 2,800 | 1.05 | | .70 | 5.14 | 4.65 | 1.58 | .71 | .... | .... | | .35 | | .70 | 5.87 | 1.52 | .60 | | 22.87 | 24.62 | Do. |
| San Pasqual | 138 | 450 | .... | .50 | 2.20 | 2.20 | 1.70 | 2.25 | .... | .... | .... | .... | .50 | .... | 1.58 | 4.30 | 1.08 | .70 | .... | 17.01 | 18.32 | L. D. Rockwood. |
| Santa Ysabel divide | 139 | 3,250 | | | | 20.29 | | | | .... | .... | .... | 1.69 | | | 17.70 | | | .... | 39.68 | 42.51 | Volcan Land & Water Co. |
| Santa Ysabel ranch house | 140 | 2,950 | | | | 16.25 | | | | .... | .... | .... | | | | 11.25 | | | | 27.50 | 30.40 | Do. |
| Santa Ysabel store | 141 | 2,980 | 1.34 | .87 | 5.55 | 5.36 | 2.03 | .67 | .34 | .... | .... | .... | .... | .83 | 2.42 | 6.24 | .25 | .53 | .... | 26.43 | 29.41 | Do. |
| Volcan Mountain | 142 | 4,800 | .... | 1.40 | 1.08 | 8.50 | 7.02 | 1.19 | 2.00 | .... | .... | .... | .... | 1.00 | .90 | 4.30 | | 9.02 | | 36.41 | 39.87 | Do. |
| Witch Creek | 143 | 2,800 | .85 | .65 | 2.85 | 6.30 | 3.65 | .... | 1.90 | .... | .... | .... | .10 | .75 | .40 | 6.90 | 1.45 | .30 | .50 | 26.60 | 29.30 | Do. |
| San Luis Rey basin: | | | | | | | | | | | | | | | | | | | | | | |
| Canfield ranch (Bonsall) | 144 | 250 | .... | .... | 1.90 | 4.38 | .45 | 1.50 | .52 | .... | .... | .... | .... | .60 | 2.00 | 2.60 | .... | .... | .... | 13.95 | 15.83 | B. F. Thorpe. |
| Damron | 145 | 2,720 | | | 19.73 | | | | .... | .... | .... | .... | | 1.27 | | 11.69 | | 1.05 | | 33.74 | 36.87 | Volcan Land & Water Co. |
| Deadmans Hole | 146 | 3,300 | .90 | .... | 5.85 | 5.35 | 2.00 | .60 | .... | .... | .... | .... | .... | .... | 4.25 | 6.00 | .... | .90 | .... | 25.85 | 27.96 | Do. |
| Eagles Nest | 147 | 4,550 | | | | [d]12.50 | | | | | | | | 6.84 | | | | | | 19.34 | 20.40 | Do. |
| Gopher Canyon (Bonsall) | 162 | 300 | .50 | | | 8.30 | | | .... | .... | .... | .... | .80 | | 4.80 | | .50 | | .... | 14.90 | 15.90 | Thos. Waite. |
| La Jolla Indian Reservation. | 148 | 2,715 | .46 | .22 | 2.52 | 7.42 | 4.00 | 1.43 | Tr. | .... | .... | .... | .10 | .57 | .52 | 5.75 | 1.38 | .22 | .50 | 25.09 | 27.95 | U. S. Weather Bureau. |
| Matagual | 149 | 2,800 | | | | 14.46 | | | .... | .... | .... | .... | | | | 10.22 | | | | 24.68 | 27.56 | Volcan Land & Water Co. |
| Mendenhall | 150 | 4,400 | 1.35 | .75 | 6.30 | 3.35 | 2.80 | .... | .... | .... | .... | .... | .45 | | 7.25 | | | 2.25 | | 24.50 | 28.32 | Do. |
| Nellie | 151 | 5,350 | .42 | .51 | 3.52 | 11.24 | 6.00 | 1.85 | Tr. | .... | .... | .19 | | 1.85 | .97 | 10.16 | 2.27 | .85 | .28 | 40.11 | 44.41 | U. S. Weather Bureau. |
| Oceanside | 152 | 60 | .55 | .20 | 1.80 | 1.23 | 1.20 | .26 | .... | .... | .... | Tr. | .54 | .08 | 2.02 | 1.60 | .06 | .31 | .... | 9.85 | 10.90 | Do. |
| Puerta La Cruz | 153 | 2,800 | | | | 14.97 | | | | .... | .... | .... | | | | 7.40 | | | | 22.37 | 23.88 | Volcan Land & Water Co. |
| San Luis Rey | 163 | 60 | .... | .67 | .44 | 3.80 | .75 | 1.60 | .23 | .... | .... | .... | .... | .66 | .07 | 4.10 | .32 | .46 | .... | 13.10 | 13.85 | B. F. Libby. |
| Valley Center | 154 | 1,300 | .56 | .40 | 4.25 | 4.15 | 2.00 | .38 | .... | .... | .... | .... | .... | .25 | .45 | 2.00 | 4.95 | .45 | .... | 19.84 | 21.03 | Volcan Land & Water Co. |
| Warner Dam | 155 | 2,710 | 1.13 | .80 | 6.37 | 7.10 | 2.34 | .76 | .... | .... | .... | .... | .22 | .50 | 2.70 | 7.73 | .04 | 1.01 | .... | 30.70 | 33.93 | Do. |
| Warner ranch house | 156 | 2,895 | | | | 12.24 | | | .... | .... | .... | .... | | 9.10 | | | | .50 | | 21.84 | 24.16 | Do. |
| Warner ranch (Rincon) | 157 | 2,900 | | | | 19.40 | | | .... | .... | .... | .... | | | | 11.03 | | | | 30.43 | 33.83 | Do. |
| Warner Springs | 158 | 3,095 | .62 | .... | 2.25 | 5.08 | 2.30 | 1.06 | .... | .... | .... | .... | .01 | .15 | .14 | 4.42 | .77 | .26 | .28 | 17.34 | 18.92 | U. S. Weather Bureau. |
| Warner's Summer Road | 159 | 2,810 | | | | 18.41 | | | | .... | .... | .... | | | | 7.12 | | | | 25.53 | 27.16 | Volcan Land & Water Co. |
| Temecula basin: | | | | | | | | | | | | | | | | | | | | | | |
| Aguanga | 201 | 1,986 | .07 | 1.30 | 3.00 | 3.80 | 1.31 | .... | .... | .... | .... | .... | .... | .... | .... | 5.00 | 2.00 | .06 | .35 | 16.88 | 17.85 | U. S. Weather Bureau. |
| Oak Grove | 160 | 2,751 | .... | .05 | 1.20 | 5.55 | 2.80 | 1.60 | .10 | .... | .... | .... | Tr. | Tr. | .... | 7.80 | 1.20 | .18 | .37 | 20.85 | 22.06 | Do. |
| Santa Ana basin: | | | | | | | | | | | | | | | | | | | | | | |
| Anaheim | 301 | 150 | .... | .87 | .... | 2.85 | 1.93 | 1.27 | .49 | .... | .... | .... | .... | .36 | .17 | 2.76 | .07 | .76 | .... | 11.53 | 15.28 | Anaheim Sugar Co. |
| Arrowhead Springs | 401 | 2,000 | .27 | .12 | 3.90 | 2.00 | .80 | .20 | .... | .... | .... | .10 | .25 | .10 | 1.90 | .60 | .08 | .45 | .... | 10.77 | 13.00 | U. S. Weather Bureau. |
| Bear Valley dam | 402 | 6,700 | 1.00 | .... | 8.83 | 12.92 | 2.16 | .17 | .... | .... | .... | .... | .44 | .... | 10.00 | | .... | .... | .... | 26.52 | 37.60 | Do. |
| Beaumont | 202 | 2,317 | .28 | 1.52 | 2.08 | 2.20 | 1.71 | .70 | .... | .... | .... | .... | .56 | .67 | 1.58 | 2.70 | .08 | .35 | .... | 14.43 | 16.16 | Do. |
| Beaumont (near) | 203 | 2,558 | .28 | .30 | .... | 5.95 | 2.55 | .61 | .74 | .... | .... | .... | .53 | .55 | 2.02 | 4.18 | .... | .63 | .... | 18.34 | 21.30 | Do. |
| Camp Baldy | 403 | 3,850 | .... | .... | 1.50 | 10.00 | 9.00 | .64 | .... | .... | .... | .... | .... | 1.80 | .... | .... | .... | .... | .84 | 23.78 | 25.88 | Do. |
| Chino | 404 | 714 | .... | .46 | .15 | 4.80 | 3.57 | 1.56 | .28 | .... | .... | .... | .80 | .27 | .... | 1.75 | 2.11 | .07 | .87 | 16.69 | 20.53 | Do. |
| Claremont | 524 | 1,200 | .02 | .38 | .07 | 4.68 | 4.41 | .82 | .42 | Tr. | .... | .... | Tr. | .61 | .16 | 1.20 | 2.19 | .... | .58 | 15.54 | 18.37 | Do. |
| Converse nursery | 405 | 6,000 | .12 | .05 | 1.02 | 6.80 | 3.64 | 1.70 | .... | .... | .... | Tr. | Tr. | 1.24 | .... | 7.42 | 1.76 | .57 | .23 | 24.55 | 28.41 | Do. |
| Corona | 204 | 615 | .37 | .... | .78 | 4.30 | 1.96 | .87 | Tr. | .... | .... | .... | .30 | .36 | .01 | 5.00 | .25 | .46 | .05 | 14.44 | 17.12 | Do. |
| Craftonville | 406 | 1,750 | .15 | 2.20 | 1.70 | 1.00 | .50 | .... | .... | .... | .... | .... | .50 | .30 | .70 | 1.90 | .... | .45 | .... | 9.40 | 10.85 | Do. |
| Dormans ranch | 407 | 2,500 | 1.20 | | 13.70 | | | 27.63 | | | .... | .... | | | 8.50 | | | 1.80 | .... | 52.83 | 57.91 | Do. |

For footnotes see p. 16.

*Precipitation, in inches, at stations in southern California, for January, 1916*—Continued.

| Station. | No. on Pl. I. | Elevation (feet). | Day of month. | | | | | | | | | | | | | | | | | Total for period. | Total for month. | Authority. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| **Santa Ana basin—Continued.** | | | | | | | | | | | | | | | | | | | | | | |
| El Casco | 205 | 1,870 | | | | 3.00 | 1.25 | 1.20 | 0.20 | | | | | 0.36 | 0.37 | 1.15 | 0.08 | 0.43 | | 8.04 | 8.91 | U. S. Weather Bureau. |
| Elsinore | 206 | 1,300 | 0.40 | 0.22 | 3.43 | 2.30 | 1.40 | .45 | | | | | 0.25 | .26 | 1.40 | 3.40 | .02 | .21 | | 13.74 | 14.83 | Do. |
| Fontana | 408 | 1,325 | .34 | | .54 | 4.21 | 1.86 | 1.28 | | | | | .06 | .72 | .98 | 2.98 | | .55 | | 13.52 | 17.51 | Do. |
| Glenn ranch | 409 | 3,256 | | .78 | .10 | 7.02 | 12.00 | 1.45 | 1.65 | | | | | .05 | | 1.98 | 3.10 | | 0.70 | 28.83 | 32.27 | Do. |
| Hemet Lake | 207 | 4,350 | | .30 | .74 | 2.75 | 2.81 | .75 | | | | | | .85 | .12 | 3.76 | .88 | .40 | | 13.36 | 16.04 | Hemet Water Co. |
| Mentone power house | 410 | 1,900 | .21 | | .14 | 1.95 | 2.99 | 1.40 | | | | | .30 | .30 | .80 | 2.94 | | .45 | | 11.48 | 14.02 | Pacific Light & Power Corp. |
| Mill Creek No. 2 | 411 | 2,950 | .28 | .12 | 2.17 | 2.88 | 1.30 | .61 | | | | | Tr. | .99 | .12 | 4.05 | .45 | .55 | | 13.52 | 15.95 | U. S. Weather Bureau. |
| Old Ranch | 302 | 90 | | .42 | .10 | 1.68 | .87 | .96 | .32 | | | | | .48 | .09 | 2.15 | 1.50 | .62 | .37 | 8.96 | 10.69 | Do. |
| Orange | 303 | 180 | | .60 | .17 | 2.42 | 1.57 | .89 | .42 | | | | | .42 | .22 | 2.01 | 1.32 | .04 | .30 | 10.38 | 13.17 | Do. |
| Pomona | 525 | 840 | | .50 | .05 | 3.50 | 4.85 | 1.05 | .55 | | | | .02 | .60 | .35 | 1.10 | 2.22 | | .63 | 15.42 | 18.74 | Do. |
| Redlands | 412 | 1,352 | | .08 | .55 | 3.44 | .98 | .79 | | | | | | .42 | .05 | 2.31 | .48 | .07 | .38 | 9.55 | 10.64 | Do. |
| Rialto (Lytle Creek) | 413 | 2,250 | .88 | .13 | 3.04 | 12.95 | 2.80 | 1.37 | | | | | .51 | 1.78 | 1.14 | 5.34 | | 1.05 | | 30.99 | 39.76 | Do. |
| Riverside | 208 | 851 | .11 | .16 | 2.26 | 1.15 | .61 | .51 | | | | | .28 | .43 | .65 | 1.67 | .03 | .47 | | 8.33 | 9.66 | Do. |
| San Bernardino | 414 | 1,054 | .24 | .04 | .80 | 5.29 | 1.18 | 1.20 | | | | | | .69 | .05 | 3.16 | .14 | .53 | .07 | 13.39 | 15.51 | Do. |
| San Jacinto | 209 | 1,560 | .14 | .08 | 1.10 | 2.78 | .96 | .82 | | | | | | .55 | | 2.17 | .46 | .11 | .16 | 9.33 | 10.71 | Do. |
| Santa Ana | 304 | 130 | .48 | .14 | 1.78 | 1.18 | .51 | .57 | | | | | | .32 | .28 | 1.62 | 1.74 | | .35 | 8.97 | 10.98 | Do. |
| Santa Ana River | 415 | 2,850 | .74 | .06 | 2.26 | 9.00 | 4.00 | | | | | | | | 1.50 | 6.25 | .20 | 2.00 | | 26.01 | 30.81 | Do. |
| Seven Oaks | 416 | 5,000 | .52 | .27 | 5.60 | 6.10 | 3.40 | .43 | | | | | .25 | 1.00 | 2.25 | 6.45 | .10 | .35 | | 26.72 | 31.10 | Do. |
| Sierra power house | 526 | 2,250 | | .83 | .10 | 5.30 | 9.40 | 1.33 | | | | | | .46 | .08 | 1.78 | 3.18 | | .75 | 23.21 | 29.43 | Pacific Light & Power Corp. |
| Squirrel Inn | 417 | 5,280 | .48 | .45 | 1.21 | c16.81 | 5.83 | 3.02 | | | | Tr. | .12 | .69 | .60 | 7.05 | .80 | 1.60 | Tr. | 38.66 | 50.29 | U. S. Weather Bureau. |
| Summit No. 2 (Cajon Pass) | 418 | 3,823 | | .24 | .26 | 2.35 | 2.65 | .40 | | | | | | | | 1.41 | | | | 7.31 | 9.65 | Do. |
| Tustin | 305 | 125 | | .30 | .12 | 1.75 | 1.06 | .78 | .38 | | | | | .41 | .26 | 1.41 | 1.68 | .07 | .43 | 8.65 | 9.84 | Do. |
| Yorba Linda | 306 | 405 | | | .52 | 3.52 | 1.17 | 1.17 | | | | | | .40 | | 3.01 | .04 | .47 | .06 | 10.36 | 13.68 | Do. |
| **San Gabriel basin:** | | | | | | | | | | | | | | | | | | | | | | |
| Alhambra | 501 | 455 | | 5.40 | | 3.00 | 1.10 | | | | | | | | | 3.00 | | .40 | | 12.90 | 17.70 | Do. |
| Arcadia | 502 | 490 | .15 | | | 5.00 | 4.00 | .56 | | | | | | 1.00 | | 1.02 | 1.60 | .50 | | 13.83 | 16.31 | Do. |
| Azusa | 503 | 540 | .01 | .30 | .02 | 6.10 | 4.76 | .95 | .16 | | | Tr. | Tr. | 1.17 | .10 | 1.26 | 1.57 | Tr. | .46 | 16.86 | 20.32 | Do. |
| Azusa power house | 504 | 750 | | .32 | .06 | 5.82 | 7.47 | .70 | .27 | | | | | 1.64 | .08 | 1.22 | 1.97 | | .43 | 19.98 | 23.21 | Pacific Light & Power Corp. |
| Bassett | 505 | 295 | | .46 | .04 | 3.20 | 3.00 | .72 | .50 | | | | | .45 | .08 | 1.40 | 1.40 | | .52 | 11.77 | 15.62 | U. S. Weather Bureau. |
| Buena Park | 506 | 77 | | .60 | .09 | 2.30 | 1.67 | .99 | | | | | | .32 | .12 | 1.68 | .77 | .90 | | 9.44 | 13.97 | Do. |
| Camp Bonita | 507 | 2,000 | | .88 | .05 | 5.18 | 8.90 | 1.60 | .20 | | | | | .76 | .05 | 1.54 | 3.32 | | .52 | 23.00 | 28.74 | Do . |
| Camp Iron Fork | 508 | 3,500 | | 1.12 | | 16.75 | | | | | | | 4.55 | | | | | .60 | | 23.02 | 29.01 | Do. |
| Covina | 509 | 560 | | .30 | 4.45 | 3.65 | .70 | | | | | | .75 | | | 1.15 | 1.65 | 1.53 | | 14.18 | 16.92 | Do. |
| Duarte | 510 | 550 | Tr. | .34 | .05 | 5.20 | 4.92 | .45 | .45 | | | | | 1.08 | .07 | 1.18 | 1.70 | | .38 | 15.82 | 19.16 | Do. |
| El Monte | 511 | 280 | | .43 | | 4.80 | 2.62 | .67 | .15 | | | .08 | .50 | | 1.25 | 1.38 | .40 | .40 | | 12.68 | 15.90 | Do. |
| Liveoak Canyon | 512 | 1,500 | .37 | .05 | 5.83 | 5.89 | 1.01 | | | | | | .76 | .14 | 1.29 | 2.33 | | .90 | | 18.57 | 22.26 | Los Angeles County. |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lordsburg | 513 | 1,040 | ..... | ..... | ..... | 7.40 | 3.68 | .90 | ..... | ..... | ..... | ..... | ..... | .83 | ..... | 3.30 | ..... | ..... | .71 | 16.82 | 20.49 | U. S. Weather Bureau. |
| Monrovia | 514 | 550 | ..... | .32 | .05 | 5.08 | 4.48 | .45 | .41 | ..... | ..... | ..... | .02 | .92 | .06 | 1.13 | 1.82 | .38 | ..... | 15.12 | 18.46 | Do. |
| Mount Lowe | 515 | 3,420 | .30 | | | 11.10 | | | ..... | ..... | ..... | 3.76 | | | | | | | ..... | 15.16 | 19.86 | Do. |
| Mount Wilson | 516 | 5,850 | .62 | .81 | .58 | 6.38 | 4.37 | 1.14 | ..... | ..... | ..... | .02 | .36 | .76 | .03 | 4.40 | .03 | .80 | ..... | 19.30 | 24.47 | Do. |
| Baldwin Acres | 517 | 385 | .33 | .05 | 3.35 | 1.98 | .68 | .06 | ..... | ..... | ..... | ..... | .05 | .40 | 1.25 | 1.30 | ..... | .33 | ..... | 9.78 | 12.74 | Los Angeles County. |
| Norwalk | 518 | 95 | ..... | .75 | .07 | 2.00 | 1.45 | .72 | .25 | ..... | ..... | ..... | ..... | .50 | .10 | 1.80 | .90 | .15 | .66 | 9.35 | 13.50 | U. S. Weather Bureau |
| Pasadena | 519 | 827 | .40 | .11 | .41 | 4.68 | 2.47 | .75 | ..... | ..... | ..... | .01 | .04 | .54 | ..... | 2.58 | .01 | .31 | ..... | 12.31 | 16.45 | Do. |
| San Gabriel | 520 | 415 | ..... | ..... | ..... | 5.30 | 2.82 | .95 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.35 | ..... | ..... | .39 | 11.81 | 15.01 | Do. |
| Santa Anita ranger station | 521 | 1,750 | ..... | .80 | .10 | 15.40 | | | | | 1.40 | | | | No record | | | | | ..... | ..... | Los Angeles County. |
| Sierra Madre | 522 | 1,400 | .37 | .10 | 5.50 | | 3.30 | .94 | ..... | ..... | ..... | 1.20 | | | .10 | 2.50 | .12 | .35 | ..... | 14.48 | 18.74 | U. S. Weather Bureau. |
| Walnut | 523 | 520 | .25 | | 6.00 | | | .75 | ..... | ..... | ..... | .50 | | 8.00 | | | | .50 | ..... | 11.00 | 14.00 | Do. |
| Los Angeles basin: | | | | | | | | | | | | | | | | | | | | | | |
| Arroyo Seco ranger station | 527 | 1,400 | .25 | ..... | .45 | 5.60 | 4.07 | .91 | ..... | ..... | ..... | Tr. | .13 | .87 | ..... | 2.50 | ..... | 1.00 | ..... | 15.78 | 20.89 | Los Angeles County. |
| Compton | 528 | 70 | ..... | .53 | .05 | 2.02 | .78 | .60 | ..... | ..... | ..... | .06 | .07 | .56 | .07 | 2.24 | .68 | ..... | .93 | 8.59 | 12.54 | U. S. Weather Bureau. |
| Dillon ranch | 529 | 2,220 | .20 | 1.40 | 1.30 | 6.20 | 3.75 | ..... | ..... | ..... | ..... | .30 | .40 | 1.10 | 1.80 | 2.80 | ..... | .75 | ..... | 19.50 | 26.30 | Los Angeles County. |
| Empire Canyon | 530 | 3,330 | ..... | .74 | ..... | 5.70 | 2.60 | .61 | .49 | ..... | ..... | ..... | ..... | 1.21 | ..... | 2.10 | ..... | .50 | ..... | 13.95 | 18.52 | Do. |
| Grassy Flat | 531 | 3,000 | ..... | .31 | ..... | 6.00 | 3.10 | .65 | ..... | ..... | ..... | ..... | ..... | .77 | ..... | 2.75 | ..... | .62 | ..... | 14.20 | 14.95 | Do. |
| Haynes Camp | 532 | 2,500 | ..... | .71 | ..... | 5.50 | 3.00 | .49 | .88 | ..... | ..... | ..... | ..... | .79 | ..... | 1.85 | ..... | .39 | ..... | 13.61 | 18.23 | Do. |
| Haynes Canyon (mouth) | 533 | 2,250 | ..... | .71 | ..... | 5.00 | 2.50 | .47 | ..... | ..... | ..... | ..... | ..... | .80 | ..... | 2.20 | ..... | .40 | ..... | 12.08 | 12.84 | Do. |
| Littlelands | 534 | 1,800 | .05 | .80 | .04 | 4.08 | 3.88 | .50 | .15 | ..... | Tr. | ..... | .08 | .60 | .04 | 1.22 | .91 | .51 | ..... | 12.36 | 16.58 | U. S. Weather Bureau. |
| Long Beach | 535 | 25 | 1.85 | ..... | .12 | 1.85 | .48 | .40 | .08 | ..... | ..... | .05 | ..... | .45 | .08 | 2.80 | .58 | .07 | .28 | 9.09 | 12.81 | Do. |
| Los Angeles | 536 | 293 | .38 | .04 | 1.07 | 4.16 | .82 | .43 | ..... | ..... | ..... | .01 | .11 | .33 | .33 | 2.28 | ..... | .43 | ..... | 10.39 | 13.30 | Do. |
| Oneonta ranch | 537 | 1,000 | ..... | .23 | .01 | 3.15 | 2.51 | .70 | .20 | ..... | ..... | ..... | .08 | .50 | .05 | .89 | 1.04 | ..... | .42 | 9.78 | 12.04 | Los Angeles County. |
| Pacoima | 538 | 1,570 | .20 | 4.50 | | | 3.05 | .57 | .15 | ..... | ..... | ..... | .10 | .55 | .05 | 1.36 | 1.09 | .40 | | 12.02 | 14.58 | U. S. Weather Bureau. |
| San Fernando | 539 | 975 | ..... | .29 | ..... | 3.97 | 2.73 | .68 | ..... | ..... | ..... | ..... | .16 | ..... | .05 | 1.62 | .61 | ..... | ..... | 10.11 | 13.39 | Do. |
| San Pedro | 540 | 25 | 1.00 | .10 | 1.00 | .40 | .50 | ..... | ..... | ..... | ..... | ..... | ..... | .40 | ..... | 1.60 | .60 | ..... | ..... | 5.60 | 7.80 | Do. |
| Sunland | 541 | 1,400 | .34 | .05 | .25 | 3.95 | 2.43 | .44 | ..... | ..... | ..... | ..... | ..... | .76 | ..... | 1.99 | ..... | .34 | ..... | 10.55 | 12.89 | Los Angeles County. |
| Tropico | 542 | 435 | .32 | ..... | 4.75 | 2.50 | .80 | .16 | ..... | ..... | ..... | ..... | .50 | ..... | 1.06 | 1.40 | ..... | .38 | ..... | 11.87 | 14.66 | U. S. Weather Bureau. |
| Wilmington | 543 | 20 | ..... | .60 | .60 | 1.90 | .80 | .65 | ..... | ..... | ..... | ..... | .70 | .60 | ..... | 2.20 | .70 | .05 | .40 | 9.20 | 13.65 | Do. |
| Coast Basin: | | | | | | | | | | | | | | | | | | | | | | |
| Ocean Park | 544 | 10 | ..... | .30 | .02 | 2.50 | 1.37 | .49 | .12 | ..... | ..... | ..... | .07 | .36 | ..... | 1.23 | 1.10 | .02 | .55 | 8.13 | 10.72 | Los Angeles County. |
| Santa Barbara | ..... | 130 | .70 | ..... | .27 | 3.36 | .73 | .52 | ..... | ..... | ..... | .09 | .27 | .92 | ..... | 3.10 | .76 | ..... | ..... | 10.72 | 17.24 | U. S. Weather Bureau. |
| Santa Monica | 545 | 110 | ..... | .69 | 5.82 | | | .63 | ..... | ..... | ..... | .15 | ..... | .63 | ..... | 2.85 | ..... | .50 | ..... | 11.27 | 14.69 | Do. |
| Santa Clara basin: | | | | | | | | | | | | | | | | | | | | | | |
| Clearwater power house | [a]547 | 2,350 | .61 | 4.40 | | | | .30 | ..... | ..... | ..... | .17 | | .25 | 1.85 | | ..... | .50 | ..... | 8.06 | 11.34 | Do. |
| Newhall | 548 | 1,200 | .89 | ..... | 2.00 | 3.03 | 1.93 | .38 | ..... | ..... | ..... | .05 | ..... | ..... | ..... | 2.67 | ..... | .43 | ..... | 11.38 | 15.72 | Do. |
| Ravenna | 546 | 2,470 | ..... | .20 | ..... | 1.25 | 1.45 | .57 | .20 | ..... | ..... | ..... | ..... | ..... | ..... | .35 | .45 | ..... | ..... | 4.47 | 5.07 | Do. |
| Sespe Camp | (b) | 1,500 | 1.88 | ..... | .62 | 5.12 | 4.08 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.75 | ..... | .62 | ..... | 16.07 | 25.00 | Sespe Light & Power Co. |
| West Saticoy | (b) | 150 | .75 | ..... | .28 | 3.00 | 1.35 | .33 | ..... | ..... | ..... | .05 | .13 | .34 | 1.88 | 1.88 | ..... | .25 | ..... | 10.24 | 14.14 | U. S. Weather Bureau. |
| Ventura basin: | | | | | | | | | | | | | | | | | | | | | | |
| Ojai Valley | (b) | 900 | .80 | ..... | ..... | 5.85 | 2.15 | .28 | ..... | ..... | ..... | ..... | .18 | .70 | ..... | 3.95 | Tr. | .47 | ..... | 14.38 | 20.82 | Do. |
| Cuyama basin: | | | | | | | | | | | | | | | | | | | | | | |
| Ozena | (b) | 3,680 | .37 | ..... | 2.80 | 1.32 | .49 | ..... | ..... | .04 | ..... | ..... | .07 | .14 | .41 | 1.00 | .09 | .18 | ..... | 6.91 | 8.38 | Do. |
| Great basin: | | | | | | | | | | | | | | | | | | | | | | |
| Cabezon | 210 | 1,790 | ..... | ..... | .20 | 4.20 | 4.60 | 2.10 | 2.30 | ..... | ..... | ..... | ..... | ..... | .50 | .10 | ..... | ..... | ..... | 14.00 | 14.20 | Southern Pacific Co. |
| Coahuila | 211 | 3,800 | .16 | ..... | 2.00 | 2.00 | 2.25 | .50 | ..... | ..... | ..... | ..... | ..... | 1.50 | 1.50 | 1.50 | .25 | .60 | ..... | 12.26 | 14.61 | U. S. Weather Bureau. |
| Fairmont | [a]549 | 2,785 | .07 | .45 | ..... | 2.58 | 3.07 | .52 | .09 | ..... | ..... | ..... | ..... | .13 | Tr. | .67 | .41 | .02 | ..... | 8.01 | 11.59 | Do. |
| Holcomb | 419 | 7,800 | .50 | ..... | .29 | 3.72 | 2.60 | .73 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1.88 | .44 | 1.50 | .30 | 11.96 | 13.28 | Do. |
| Nenach | [a]550 | 3,000 | ..... | .25 | 1.40 | | .90 | .25 | ..... | ..... | ..... | .04 | ..... | ..... | ..... | .12 | ..... | ..... | .09 | 3.05 | 3.70 | Do. |
| Palm Springs | 212 | 680 | ..... | ..... | .30 | 1.00 | 1.00 | .75 | .35 | ..... | ..... | ..... | ..... | ..... | ..... | 1.00 | ..... | ..... | ..... | 4.40 | 5.20 | Southern Pacific Co. |

For footnotes see p. 16.

*Precipitation, in inches, at stations in southern California, for January, 1916*—Continued.

| Station. | No. on Pl. I. | Elevation (feet). | Day of month. | | | | | | | | | | | | | | | | | Total for period. | Total for month. | Authority. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | | |
| Great Basin—Continued. | | | | | | | | | | | | | | | | | | | | | | |
| San Felipe | 161 | 3,600 | | | | 14.50 | | | ..... | ..... | | 0.20 | | ..... | | 9.00 | | 0.20 | ..... | 23.90 | 25.40 | Volcan Land & Water Co. |
| Valyermo | 551 | 3,750 | 0.08 | ..... | .20 | 2.77 | 1.72 | 0.39 | 0.23 | ..... | ..... | ..... | ..... | ..... | ..... | 0.58 | ..... | Tr. | ..... | 5.97 | 6.31 | U. S. Weather Bureau. |

[a] Not shown on maps in pocket.
[b] Ventura County, not shown on maps in pocket.
[c] Greatest amount for one day ever recorded in California.
[d] Record is total for period Jan. 9 to 20.

NOTE.—In general, the maximum precipitation for the first storm occurred on January 17 and for the second storm on January 27. Various methods were used in recording the observations. At the regular stations of the Weather Bureau precipitation is recorded for the 24-hour period ending at midnight; at the cooperative stations the observations are made either late in the afternoon, near sunset, or in the morning, and the amount recorded is for the preceding 24 hours. At the stations maintained by private parties the observations are usually made at 7 a. m. and the general practice is to record the amount as the precipitation for the preceding day, although at some stations it is given as the precipitation for the day on which the measurement was made. Station numbers refer to location shown on maps in pocket, as follows: San Diego County, 101-163; Riverside County, 201-212; Orange County, 301-306; San Bernardino County, 401-419; Los Angeles County, 501-551.

## RAINFALL IN EARLIER YEARS.

In order that the records of precipitation for January, 1916, may be compared with those of preceding years, complete monthly records of rainfall at San Diego, Los Angeles, and Santa Barbara are given in the following tables. The precipitation for January, 1916, was the maximum for that month recorded at these stations. It was, however, exceeded by the precipitation in February, 1884, at Los Angeles and San Diego, and by that of March, 1867, at San Diego. At Santa Barbara the rainfall of January, 1916, exceeded that of the next highest month, December, 1867, by 36 per cent. See table on page 20.

*Precipitation, in inches, at San Diego, Cal., 1850–1916.*

| Season. | July. | August. | September. | October. | November. | December. | January. | February. | March. | April. | May. | June. | Seasonal. | Year. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1850...... | ...... | ...... | ...... | ...... | ...... | ...... | 0 | 1.13 | 1.00 | 0.09 | 0 | 0.68 | ...... | 1850 | 7.84 |
| 1850–51... | 0 | 0 | 0 | 0.19 | 2.82 | 1.93 | 0.03 | 1.51 | .34 | .87 | 0.71 | .01 | 8.41 | 1851 | 7.49 |
| 1851–52... | 0 | 0 | 0.02 | .01 | .25 | 3.74 | .58 | 1.84 | 1.87 | .85 | .32 | 0 | 9.48 | 1852 | 11.87 |
| 1852–53... | 0 | 0.40 | 0 | .06 | 1.45 | 4.50 | .50 | .20 | 1.52 | .25 | 2.10 | .05 | 11.03 | 1853 | 7.88 |
| 1853–54... | 0 | .21 | 0 | 0 | 1.28 | 1.77 | .99 | 2.56 | 1.88 | .89 | .18 | .01 | 9.77 | 1854 | 11.63 |
| 1854–55... | 0.07 | 1.36 | .09 | .27 | .04 | 3.29 | 1.97 | 3.59 | 1.30 | 1.52 | .06 | 0 | 13.56 | 1855 | 11.15 |
| 1855–56... | 0 | .04 | 0 | .11 | 2.15 | .41 | 1.27 | 1.86 | 1.59 | 2.17 | .29 | 0 | 9.89 | 1856 | 9.77 |
| 1856–57... | 0 | 0 | .07 | 0 | 1.22 | 1.30 | .26 | 1.76 | 0 | .04 | 0.08 | .03 | 4.76 | 1857 | 6.15 |
| 1857–58... | 0 | .02 | .01 | .49 | 2.16 | 1.30 | 1.52 | .44 | 1.24 | .17 | 0 | .19 | 7.54 | 1858 | 7.55 |
| 1858–59... | 0 | .04 | .10 | .47 | .28 | 3.10 | 0 | 1.89 | .20 | .36 | .17 | 0 | 6.61 | 1859 | 6.10 |
| 1859–60... | .02 | 0 | 0 | .18 | 1.49 | 1.79 | .72 | 1.49 | .15 | .65 | .04 | .05 | 6.58 | 1860 | 9.11 |
| 1860–61... | .14 | 0 | 0 | 0 | 2.88 | 2.99 | .82 | .79 | .05 | .04 | 0 | .19 | 7.90 | 1861 | 7.92 |
| 1861–62... | 0 | 0 | 1.59 | .05 | 1.19 | 3.20 | 5.56 | 1.39 | .97 | .105 | .16 | .48 | 15.64 | 1862 | 11.59 |
| 1862–63... | .11 | 0 | 0 | .89 | .05 | .93 | .32 | 1.09 | .33 | .13 | .02 | 0 | 3.87 | 1863 | 3.02 |
| 1863–64... | 0 | 0 | .36 | 0 | .73 | .04 | .04 | 2.50 | .20 | .01 | 1.25 | .01 | 5.14 | 1864 | 7.61 |
| 1864–65... | .11 | 0 | 0 | .04 | 2.41 | 1.04 | 1.28 | 3.00 | 0 | .56 | 0 | .01 | 8.45 | 1865 | 7.52 |
| 1965–66... | 1.29 | 0 | 0 | .02 | .52 | .84 | 5.05 | 3.43 | 1.47 | .11 | .09 | 0 | 12.82 | 1866 | 12.31 |
| 1866–67... | 0 | .10 | 0 | 0 | .24 | 1.82 | 2.32 | .85 | 7.88 | .48 | .04 | 0 | 13.73 | 1867 | 15.72 |
| 1867–68... | 0 | .30 | 0 | .34 | .45 | 3.06 | 3.37 | 1.63 | .73 | 1.20 | .15 | 0 | 11.23 | 1868 | 11.16 |
| 1868–69... | .51 | 0 | .05 | 0 | 2.00 | 1.52 | 2.88 | 1.88 | 1.98 | .53 | .33 | 0 | 11.68 | 1869 | 10.96 |
| 1869–70... | .05 | 0 | 0 | .05 | 2.32 | .94 | .54 | .77 | .33 | .20 | .28 | 0 | 5.48 | 1870 | 4.37 |
| 1870–71... | .04 | .07 | 0 | 1.54 | .18 | .42 | .52 | 1.35 | .01 | .70 | .34 | 0 | 5.17 | 1871 | 5.64 |
| 1871–72... | 0 | 0 | 0 | 0 | 1.33 | 1.39 | .99 | 1.63 | .46 | .26 | .12 | 0 | 7.18 | 1872 | 5.07 |
| 1872–73... | 0 | .18 | 0 | 0 | 0 | 1.43 | .44 | 4.21 | .11 | .10 | .03 | 0 | 6.50 | 1873 | 13.07 |
| 1873–74... | 0 | 1.95 | 0 | 0 | .77 | 5.46 | 3.11 | 3.73 | 1.20 | .34 | .32 | 0 | 16.88 | 1874 | 10.91 |
| 1874–75... | .12 | 0 | .13 | .53 | .88 | .55 | 2.38 | .37 | .45 | .12 | .20 | .02 | 5.73 | 1875 | 6.80 |
| 1875–76... | 0 | .21 | .39 | 0 | 2.25 | .41 | 2.47 | 2.44 | 1.78 | .06 | .05 | .05 | 10.11 | 1876 | 7.24 |
| 1876–77... | .08 | .06 | .03 | .08 | .04 | .15 | 1.05 | .18 | 1.44 | .26 | .43 | Tr. | 3.75 | 1877 | 8.12 |
| 1877–78... | 0 | 0 | 0 | .81 | .06 | 3.89 | 1.45 | 4.83 | 1.41 | 2.91 | .58 | .16 | 16.10 | 1878 | 13.87 |
| 1878–79... | 0 | 0 | 0 | .96 | 0 | 1.57 | 3.54 | 1.04 | .10 | .60 | Tr. | .07 | 7.88 | 1879 | 14.71 |
| 1879–80... | 0 | 0 | 0 | .29 | 2.77 | 6.30 | .61 | 1.50 | 1.43 | 1.34 | .06 | .06 | 14.36 | 1880 | 10.37 |
| 1880–81... | .09 | .32 | 0 | .53 | .28 | 4.15 | .52 | .45 | 1.88 | 1.35 | .04 | .05 | 9.66 | 1881 | 5.00 |
| 1881–82... | 0 | .01 | .04 | .24 | .12 | .30 | 4.53 | 2.55 | 1.02 | .45 | .18 | .07 | 9.51 | 1882 | 9.74 |
| 1882–83... | 0 | Tr. | .01 | .41 | .39 | .13 | 1.09 | .95 | .41 | .31 | 1.14 | .08 | 4.92 | 1883 | 8.01 |
| 1883–84... | 0 | 0 | 0 | 2.01 | .20 | 1.82 | 1.34 | 9.05 | 6.23 | 2.84 | 2.17 | .31 | 25.97 | 1884 | 27.59 |
| 1884–85... | 0 | Tr. | .07 | .35 | .11 | 5.12 | .35 | .02 | .78 | 1.20 | .61 | .06 | 8.67 | 1885 | 5.73 |
| 1885–86... | Tr. | .13 | Tr. | .31 | 1.56 | .71 | 6.95 | 1.51 | 3.73 | 1.95 | .04 | .07 | 16.96 | 1886 | 15.35 |
| 1886–87... | Tr. | Tr. | 0 | .05 | .95 | .10 | .04 | 4.51 | .02 | 2.14 | .47 | .04 | 8.32 | 1887 | 10.45 |
| 1887–88... | .01 | Tr. | Tr. | Tr. | 2.08 | 1.14 | 1.96 | 1.48 | 2.79 | .10 | .22 | .04 | 9.82 | 1888 | 11.57 |
| 1888–89... | .01 | Tr. | .04 | .26 | 1.83 | 2.84 | 1.72 | 1.80 | 2.20 | .19 | .03 | .10 | 11.02 | 1889 | 16.03 |
| 1889–90... | Tr. | .04 | Tr. | 2.12 | .12 | 7.71 | 2.79 | 1.70 | .41 | .05 | .08 | 0 | 15.02 | 1890 | 8.02 |
| 1890–91... | 0 | Tr. | .65 | .01 | .72 | 1.61 | 1.21 | 4.84 | .27 | .76 | .35 | .05 | 10.47 | 1891 | 8.99 |
| 1891–92... | Tr. | 0 | .08 | .04 | .10 | 1.29 | 1.58 | 2.96 | .96 | .41 | 1.15 | .13 | 8.70 | 1892 | 9.09 |
| 1892–93... | 0 | .05 | Tr. | .22 | .91 | .69 | .78 | .47 | 5.50 | .22 | .39 | Tr. | 9.26 | 1893 | 10.29 |
| 1893–94... | Tr. | 0 | 0 | .11 | .91 | 1.91 | .29 | .49 | 1.05 | .11 | .09 | .01 | 4.97 | 1894 | 4.35 |

*Precipitation, in inches, at San Diego, Cal., 1850–1916*—Continued.

| Season. | July. | August. | September. | October. | November. | December. | January. | February. | March. | April. | May. | June. | Seasonal. | Year. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1894–95... | 0 | 0.04 | 0.01 | Tr. | 0 | 2.26 | 7.33 | 0.53 | 1.43 | 0.11 | 0.19 | 0 | 11.90 | 1895 | 11.33 |
| 1895–96... | 0 | 0 | .01 | .27 | 1.19 | .27 | 1.27 | .02 | 2.89 | .25 | .03 | .01 | 6.21 | 1896 | 8.73 |
| 1896–97... | Tr. | .13 | Tr. | .97 | .98 | 2.18 | 3.13 | 2.72 | 1.53 | .02 | .12 | T. | 11.78 | 1897 | 8.93 |
| 1897–98... | .01 | Tr. | Tr. | 1.06 | .02 | .32 | 1.71 | .06 | .91 | .22 | .66 | .02 | 4.99 | 1898 | 4.67 |
| 1898–99... | 0 | 0 | .07 | 0 | .15 | .87 | 2.34 | .30 | .85 | .29 | .10 | .27 | 5.24 | 1899 | 6.08 |
| 1899–1900. | 0 | .07 | 0 | .35 | .86 | .65 | .69 | .03 | .53 | 1.26 | 1.45 | .08 | 5.97 | 1900 | 5.77 |
| 1900–01... | 0 | Tr. | Tr. | .30 | 1.43 | 0 | 2.08 | 4.77 | 1.07 | .01 | .77 | .02 | 10.45 | 1901 | 9.49 |
| 1901–02... | Tr. | Tr. | .06 | .28 | .41 | .02 | 1.70 | 1.57 | 1.86 | .21 | .06 | Tr. | 6.17 | 1902 | 11.49 |
| 1902–03... | .92 | Tr. | Tr. | .06 | 1.53 | 3.58 | .69 | 2.27 | 1.17 | 1.40 | .14 | Tr. | 11.76 | 1903 | 6.09 |
| 1903–04... | 0 | Tr. | Tr. | .07 | Tr. | .35 | .04 | 1.50 | 2.17 | .15 | .12 | 0 | 4.40 | 1904 | 6.61 |
| 1904–05... | 0 | Tr. | Tr. | .17 | 0 | 2.46 | 2.16 | 5.90 | 2.98 | .30 | .35 | Tr. | 14.32 | 1905 | 16.36 |
| 1905–06... | .16 | 0 | .50 | .25 | 3.38 | .38 | .98 | 2.62 | 4.68 | .98 | .72 | .03 | 14.68 | 1906 | 14.90 |
| 1906–07... | Tr. | .10 | .12 | .03 | .62 | 4.02 | 3.27 | .45 | 1.62 | .13 | .07 | .19 | 10.62 | 1907 | 7.95 |
| 1907–08... | .03 | 0 | 0 | 1.71 | .05 | .43 | 2.80 | 2.41 | .61 | .35 | .16 | 0 | 8.55 | 1908 | 8.59 |
| 1908–09... | 0 | .64 | .20 | .15 | 1.00 | .27 | 3.57 | 1.76 | 2.62 | .02 | Tr. | Tr. | 10.23 | 1909 | 14.14 |
| 1909–10... | Tr. | Tr. | .02 | 0 | 2.39 | 3.76 | 2.00 | .19 | 1.30 | .08 | .05 | 0 | 9.79 | 1910 | 5.75 |
| 1910–11... | .01 | .05 | .17 | 1.35 | .40 | .15 | 3.35 | 4.92 | .92 | .65 | .01 | .01 | 11.99 | 1911 | 11.77 |
| 1911–12... | .12 | 0 | .10 | .28 | .02 | 1.39 | .66 | 0 | 5.72 | 2.13 | .17 | .16 | 10.72 | 1912 | 10.56 |
| 1912–13... | .14 | .26 | 0 | .89 | .40 | .03 | 1.19 | 2.40 | .42 | .08 | .07 | .09 | 5.97 | 1913 | 7.30 |
| 1913–14... | .06 | .02 | .02 | Tr. | 2.23 | .72 | 3.59 | 1.90 | .36 | .85 | .08 | 0 | 9.83 | 1914 | 10.90 |
| 1914–15... | 0 | 0 | Tr. | 1.05 | .86 | 2.21 | 4.91 | 3.62 | .33 | 1.15 | .28 | Tr. | 14.41 | 1915 | 13.62 |
| 1915–16... | Tr. | 0 | Tr. | 0 | .73 | 2.60 | 7.56 | .66 | .98 | .01 | .01 | Tr. | 12.55 | 1916 | 11.56 |
| 1916–17... | .02 | .01 | .25 | .87 | .05 | 1.14 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .... | ...... |
| Maximum | 1.29 | 1.95 | 1.59 | 2.12 | 3.38 | 7.71 | 7.56 | 9.05 | 7.88 | 2.91 | 2.17 | .68 | 25.97 | .... | 27.59 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .01 | 0 | 0 | 3.87 | .... | 3.02 |
| Mean..... | .06 | .10 | .08 | .36 | .94 | 1.80 | 1.92 | 1.94 | 1.46 | .62 | .31 | .06 | 9.74 | .... | 9.66 |

*Precipitation, in inches, at Los Angeles, Cal., 1877–1916.*

| Season. | July. | August. | September. | October. | November. | December. | January. | February. | March. | April. | May. | June. | Seasonal. | Year. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1877–78... | 0 | 0 | 0 | 0.86 | 0.45 | 3.93 | 3.33 | 7.68 | 2.57 | 1.71 | 0.66 | 0.07 | 21.26 | 1878 | 20.86 |
| 1878–79... | 0 | Tr. | 0 | .14 | Tr. | 4.70 | 3.59 | .97 | .49 | 1.19 | .24 | .03 | 11.35 | 1879 | 17.41 |
| 1879–80... | 0 | 0 | 0 | .93 | 3.44 | 6.53 | 1.33 | 1.56 | 1.45 | 5.06 | .04 | 0 | 20.34 | 1880 | 18.65 |
| 1880–81... | Tr. | Tr. | 0 | .14 | .67 | 8.40 | 1.43 | .36 | 1.66 | .46 | .01 | 0 | 13.13 | 1881 | 5.53 |
| 1881–82... | 0 | Tr. | Tr. | .82 | .27 | .52 | 1.01 | 2.66 | 2.66 | 1.83 | .63 | Tr. | 10.40 | 1882 | 10.74 |
| 1882–83... | 0 | 0 | Tr. | .05 | 1.82 | .08 | 1.62 | 3.47 | 2.87 | .15 | 2.02 | .03 | 12.11 | 1883 | 14.14 |
| 1883–84... | Tr. | 0 | 0 | 1.42 | 0 | 2.56 | 3.15 | 13.37 | 12.36 | 3.58 | .35 | 1.39 | 38.18 | 1884 | 40.29 |
| 1884–85... | Tr. | Tr. | Tr. | .39 | 1.06 | 4.64 | 1.05 | Tr. | .01 | 2.00 | .06 | Tr. | 9.21 | 1885 | 10.53 |
| 1885–86... | Tr. | Tr. | Tr. | .26 | 5.52 | 1.63 | 7.72 | 1.38 | 2.50 | 3.29 | 0 | .01 | 22.31 | 1886 | 16.72 |
| 1886–87... | 0.24 | 0.21 | 0 | .01 | 1.18 | .18 | .20 | 9.25 | .24 | 2.30 | .20 | .04 | 14.05 | 1887 | 16.02 |
| 1887–88... | .07 | 0 | 0.15 | .12 | .78 | 2.67 | 6.03 | .77 | 3.15 | .11 | .02 | Tr. | 13.87 | 1888 | 20.82 |
| 1888–89... | .03 | .08 | Tr. | .36 | 4.01 | 6.26 | .25 | .92 | 6.48 | .27 | .62 | 0 | 19.28 | 1889 | 33.26 |
| 1889–90... | 0 | .28 | .33 | 6.96 | 1.35 | 15.80 | 7.83 | 1.36 | .66 | .22 | .03 | .02 | 34.84 | 1890 | 12.69 |
| 1890–91... | 0 | .03 | .06 | .03 | .13 | 2.32 | .25 | 8.56 | .41 | 1.26 | .31 | 0 | 13.36 | 1891 | 12.84 |
| 1891–92... | Tr. | 0 | .06 | 0 | 0 | 1.99 | .88 | 3.19 | 3.39 | .22 | 2.06 | .06 | 11.85 | 1892 | 18.72 |
| 1892–93... | 0 | .01 | 0 | .33 | 4.40 | 4.18 | 6.29 | 2.27 | 8.52 | .19 | .06 | .03 | 26.28 | 1893 | 21.96 |
| 1893–94... | 0 | 0 | Tr. | .75 | .20 | 3.65 | .94 | .49 | .37 | .13 | .20 | Tr. | 6.73 | 1894 | 7.51 |
| 1894–95... | Tr. | .01 | .73 | .02 | 0 | 4.62 | 5.84 | .46 | 3.77 | .46 | .19 | .01 | 16.11 | 1895 | 12.55 |
| 1895–96... | Tr. | Tr. | Tr. | .24 | .80 | .78 | 3.23 | Tr. | 2.97 | .19 | .30 | Tr. | 8.51 | 1896 | 11.80 |
| 1896–97... | .02 | .01 | Tr. | 1.30 | 1.66 | 2.12 | 3.70 | 5.62 | 2.31 | .02 | .10 | Tr. | 16.86 | 1897 | 14.28 |
| 1897–98... | Tr. | 0 | 0 | 2.47 | .01 | .05 | 1.26 | .51 | .98 | .03 | 1.75 | Tr. | 7.06 | 1898 | 4.83 |
| 1898–99... | .07 | Tr. | .02 | .09 | Tr. | .12 | 2.64 | .04 | 1.81 | .18 | .04 | .58 | 5.59 | 1899 | 8.69 |
| 1899–1900. | 0 | .01 | Tr. | 1.59 | .90 | .90 | 1.17 | Tr. | .99 | .54 | 1.81 | Tr. | 7.91 | 1900 | 11.30 |
| 1900–01... | Tr. | Tr. | Tr. | .26 | 6.53 | Tr. | 2.49 | 4.38 | .45 | .68 | 1.50 | Tr. | 16.29 | 1901 | 11.96 |
| 1901–02... | Tr. | .09 | .03 | 1.88 | .46 | 0 | 1.62 | 3.35 | 2.98 | .16 | .03 | Tr. | 10.60 | 1902 | 13.12 |
| 1902–03... | Tr. | Tr. | Tr. | .40 | 2.08 | 2.50 | 2.10 | 1.52 | 6.93 | 3.77 | Tr. | .02 | 19.32 | 1903 | 14.77 |
| 1903–04... | 0 | Tr. | .43 | Tr. | 0 | Tr. | .14 | 2.68 | 4.50 | .97 | Tr. | Tr. | 8.72 | 1904 | 11.88 |
| 1904–05... | Tr. | .17 | .28 | .69 | 0 | 2.45 | 2.57 | 6.06 | 6.00 | .35 | .95 | 0 | 19.52 | 1905 | 19.19 |
| 1905–06... | 0 | 0 | Tr. | .08 | 2.98 | .20 | 3.85 | 2.47 | 7.35 | .69 | 1.02 | .01 | 18.65 | 1906 | 21.46 |
| 1906–07... | .02 | .03 | .05 | 0 | .85 | 5.12 | 7.02 | 1.83 | 4.12 | .16 | .07 | .03 | 19.30 | 1907 | 15.30 |
| 1907–08... | 0 | 0 | Tr. | 1.19 | Tr. | .88 | 5.04 | 3.66 | .18 | .52 | .25 | 0 | 11.72 | 1908 | 13.74 |
| 1908–09... | Tr. | .08 | 1.22 | .25 | 1.08 | 1.46 | 7.27 | 5.20 | 2.51 | Tr. | 0 | .11 | 19.18 | 1909 | 23.92 |
| 1909–10... | 0 | Tr. | .04 | .28 | 1.51 | 7.00 | 1.53 | .11 | 1.86 | .30 | 0 | 0 | 12.63 | 1910 | 4.89 |
| 1910–11... | .04 | Tr. | .01 | .82 | .15 | .07 | 6.70 | 2.91 | 5.15 | .28 | .02 | .03 | 16.18 | 1911 | 17.85 |
| 1911–12... | Tr. | 0 | 1.23 | .16 | .10 | 1.27 | .07 | 0 | 6.99 | 1.66 | .12 | 0 | 8.60 | 1912 | 9.78 |
| 1912–13... | Tr. | 0 | 0 | .56 | .35 | .03 | 2.01 | 9.16 | .33 | .35 | .05 | .58 | 13.42 | 1913 | 17.17 |
| 1913–14... | Tr. | Tr. | .03 | Tr. | 3.00 | 1.66 | 10.35 | 7.04 | .58 | .47 | .43 | .09 | 23.65 | 1914 | 23.91 |
| 1914–15... | .01 | 0 | 0 | .31 | .20 | 3.73 | 5.42 | 5.09 | .60 | .81 | .88 | Tr. | 17.05 | 1915 | 16.67 |
| 1915–16... | 0 | 0 | Tr. | 0 | 1.35 | 2.52 | 13.30 | 1.82 | .90 | Tr. | .03 | 0 | 19.92 | 1916 | 23.29 |
| 1916–17... | 0 | Tr. | .77 | 2.71 | .09 | 3.67 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .... | ...... |
| Maximum | .24 | .28 | 1.23 | 6.96 | 6.53 | 15.80 | 13.30 | 13.37 | 12.36 | 5.06 | 2.06 | 1.39 | 38.18 | .... | 40.29 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | .07 | 0 | .01 | Tr. | 0 | 0 | 5.59 | .... | 4.83 |
| Mean..... | .01 | .03 | .14 | .72 | 1.23 | 2.78 | 3.49 | 3.13 | 2.92 | .94 | .44 | .08 | 15.78 | .... | 15.92 |

*Precipitation, in inches, at Santa Barbara, Cal., 1867–1916.*

| Season. | July. | August. | September. | October. | November. | December. | January. | February. | March. | April. | May. | June. | Seasonal. | Year. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1867–68... | [a]0.02 | [a]0.01 | 0 | 0 | 2.31 | 12.67 | 3.97 | 2.00 | 1.08 | 2.44 | 0.72 | 0 | [a]25.22 | 1868 | 15.72 |
| 1868–69... | 0 | 0 | 0 | 0 | 1.25 | 4.26 | 3.26 | 2.12 | 4.22 | .46 | .20 | 0 | 15.77 | 1869 | 11.78 |
| 1869–70... | 0 | 0 | 0 | 0.30 | .65 | .57 | .25 | 5.87 | .83 | .99 | .74 | 0.07 | 10.27 | 1870 | 11.47 |
| 1870–71... | 0 | 0 | 0 | 1.04 | .27 | 1.41 | .86 | 2.92 | .02 | 2.02 | .37 | 0 | 8.91 | 1871 | 14.67 |
| 1871–72... | 0 | 0 | 0 | .09 | 1.83 | 6.56 | 2.53 | 1.81 | .18 | 1.80 | 0 | .14 | 14.94 | 1872 | 10.87 |
| 1872–73... | 0 | .02 | .05 | 0 | 0 | 4.34 | .58 | 5.48 | .05 | 0 | 0 | 0 | 10.52 | 1873 | 11.64 |
| 1873–74... | 0 | 0 | 0 | 0 | .27 | 5.26 | 4.54 | 3.17 | .78 | .28 | .14 | 0 | 14.44 | 1874 | 12.12 |
| 1874–75... | 0 | 0 | 0 | 1.91 | 1.30 | 0 | 14.81 | .18 | .38 | .10 | 0 | 0 | 18.71 | 1875 | 22.34 |
| 1875–76... | 0 | 0 | 0 | 0 | 6.53 | .31 | 7.56 | 5.67 | 2.73 | .27 | 0 | 0 | 23.07 | 1876 | 16.55 |
| 1876–77... | 0 | 0 | 0 | .32 | 0 | 0 | 2.72 | 0 | .82 | .18 | .45 | 0 | 4.49 | 1877 | 8.61 |
| 1877–78... | 0 | 0 | 0 | 0 | 1.32 | 3.12 | 7.17 | 11.73 | 2.47 | 3.34 | .29 | .07 | 29.51 | 1878 | 30.55 |
| 1878–79... | 0 | 0 | 0 | .32 | 0 | 5.16 | 5.24 | .71 | .34 | 1.60 | .21 | 0 | 13.58 | 1879 | 14.70 |
| 1879–80... | 0 | 0 | 0 | .41 | 1.62 | 4.57 | 1.30 | 10.86 | 1.15 | 5.73 | 0 | 0 | 25.04 | 1880 | 29.30 |
| 1880–81... | 0 | 0 | 0 | .25 | .28 | 9.73 | 2.83 | .30 | 1.25 | .59 | 0 | 0 | 15.23 | 1881 | 8.16 |
| 1881–82... | 0 | 0 | .44 | 1.47 | .33 | .95 | 1.13 | 2.38 | 5.74 | 1.63 | 0 | .20 | 14.27 | 1882 | 12.32 |
| 1882–83... | 0 | 0 | 0 | .37 | .77 | .10 | 2.18 | 2.92 | 3.64 | .29 | 2.79 | .35 | 13.41 | 1883 | 16.25 |
| 1883–84... | 0 | 0 | 0 | 1.32 | 0 | 2.76 | 6.33 | 9.68 | 9.77 | 2.60 | .39 | 1.62 | 34.47 | 1884 | 38.82 |
| 1884–85... | 0 | 0 | 0 | 1.02 | .79 | 6.62 | 1.23 | .07 | .35 | 3.00 | 0 | 0 | 13.08 | 1885 | 17.15 |
| 1885–86... | 0 | 0 | 0 | .19 | 9.84 | 2.47 | 5.12 | 1.19 | 2.03 | 3.40 | 0 | 0 | 24.24 | 1886 | 13.86 |
| 1886–87... | 0 | 0 | 0 | .39 | .87 | .86 | .31 | 8.64 | .13 | 1.43 | .33 | .03 | 12.99 | 1887 | 17.09 |
| 1887–88... | 0 | 0 | .38 | .31 | 1.10 | 4.43 | 10.15 | 1.30 | 3.86 | .16 | .02 | Tr. | 21.71 | 1888 | 26.80 |
| 1888–89... | Tr. | Tr. | .03 | .07 | 5.62 | 5.59 | .29 | 1.29 | 7.31 | .49 | .76 | .13 | 21.58 | 1889 | 32.77 |
| 1889–90... | 0 | 0 | 0 | 8.65 | 3.21 | 10.64 | 5.32 | 2.96 | 1.10 | .31 | .18 | .06 | 32.43 | 1890 | 15.49 |
| 1890–91... | 0 | 0 | 1.50 | .05 | .48 | 3.53 | .45 | 7.92 | 1.56 | 1.57 | .30 | 0 | 17.36 | 1891 | 14.38 |
| 1891–92... | 0 | 0 | .15 | 0 | 0 | 2.43 | 1.10 | 2.55 | 2.95 | .46 | 1.12 | 0 | 10.76 | 1892 | 19.37 |
| 1892–93... | 0 | 0 | 0 | .26 | 4.27 | 6.66 | 4.41 | 3.10 | 7.80 | .38 | .09 | 0 | 26.97 | 1893 | 19.61 |
| 1893–94... | 0 | 0 | 0 | .82 | .07 | 2.94 | .99 | .76 | .29 | .24 | .91 | 0 | 7.02 | 1894 | 10.09 |
| 1894–95... | .12 | Tr. | 1.36 | .68 | .07 | 4.67 | 6.25 | .67 | 1.99 | .46 | .02 | .05 | 16.34 | 1895 | 11.69 |
| 1895–96... | Tr. | 0 | 0 | .55 | .77 | .93 | 6.84 | 0 | 2.37 | 1.78 | .08 | .05 | 13.37 | 1896 | 18.87 |
| 1896–97... | .40 | 0 | 0 | .92 | 3.51 | 2.92 | 4.35 | 3.65 | 2.73 | .02 | 0 | 0 | 18.50 | 1897 | 12.19 |
| 1897–98... | 0 | 0 | 0 | 1.44 | 0 | 0 | .63 | 1.39 | .28 | Tr. | 1.25 | 0 | 4.99 | 1898 | 7.22 |
| 1898–99... | Tr. | 0 | 3.17 | .14 | 0 | .36 | 4.48 | 0 | 2.78 | .64 | 0 | .78 | 12.35 | 1899 | 15.06 |
| 1899–1900. | 0 | 0 | 0 | 2.06 | 1.97 | 2.35 | 2.32 | .05 | 1.58 | .42 | 1.90 | .01 | 12.66 | 1900 | 10.50 |
| 1900–01... | .02 | Tr. | .04 | .15 | 3.99 | .02 | 4.86 | 3.65 | .16 | 2.07 | .34 | .10 | 15.40 | 1901 | 15.27 |
| 1901–02... | .06 | .09 | .36 | 2.42 | 1.16 | Tr. | 1.36 | 4.40 | 2.89 | 1.40 | .07 | 0 | 14.21 | 1902 | 17.85 |
| 1902–03... | 0 | 0 | 0 | 1.48 | 4.01 | 2.24 | 2.06 | 1.63 | 6.12 | 2.91 | .27 | .02 | 20.74 | 1903 | 13.06 |
| 1903–04... | 0 | 0 | Tr. | Tr. | .05 | Tr. | .46 | 4.69 | 4.40 | 1.89 | .09 | 0 | 11.58 | 1904 | 20.82 |
| 1904–05... | 0 | .10 | 7.15 | .51 | Tr. | 1.53 | 3.73 | 8.22 | 6.40 | .51 | 1.44 | .05 | 29.64 | 1905 | 21.93 |
| 1905–06... | .18 | 0 | .03 | .16 | 1.14 | .07 | 4.26 | 3.67 | 9.96 | .83 | 2.40 | Tr. | 22.70 | 1906 | 27.97 |
| 1906–07... | Tr. | .04 | 0 | 0 | .35 | 6.46 | 12.46 | 2.34 | 5.64 | .27 | Tr. | .16 | 27.72 | 1907 | 28.93 |
| 1907–08... | 0 | .03 | Tr. | 6.23 | Tr. | 1.80 | 4.29 | 5.96 | .21 | .49 | .20 | 0 | 19.21 | 1908 | 16.83 |
| 1908–09... | 0 | 0 | 1.16 | .20 | 1.84 | 2.48 | 15.67 | 7.92 | 6.91 | 0 | .08 | .08 | 36.29 | 1909 | 43.23 |
| 1909–10... | Tr. | .01 | .17 | .57 | 2.34 | 9.53 | 2.91 | .08 | 3.62 | .39 | 0 | 0 | 19.62 | 1910 | 10.95 |
| 1910–11... | .02 | Tr. | 2.56 | .29 | .33 | .75 | 14.21 | 4.92 | 7.76 | 1.02 | .03 | .05 | 31.94 | 1911 | 30.74 |
| 1911–12... | Tr. | 0 | .12 | .28 | .02 | 2.33 | .42 | 0 | 9.48 | 2.12 | 1.58 | Tr. | 14.35 | 1912 | 14.09 |
| 1912–13... | Tr. | 0 | Tr. | .28 | .21 | Tr. | 3.14 | 6.58 | .64 | 1.04 | .19 | .50 | 12.58 | 1913 | 18.56 |
| 1913–14... | .09 | .07 | .17 | Tr. | 3.43 | 2.71 | 15.91 | 7.30 | .95 | .70 | .03 | .16 | 31.52 | 1914 | 29.64 |
| 1914–15... | .05 | 0 | 0 | .12 | .04 | 4.38 | 4.94 | 8.03 | 1.15 | .97 | 1.57 | Tr. | 21.25 | 1915 | 21.42 |
| 1915–16... | 0 | 0 | .05 | 0 | .65 | 4.06 | 17.24 | 1.89 | 1.71 | .30 | Tr. | 0 | 25.90 | 1916 | 32.19 |
| 1916–17... | 0 | .11 | 1.90 | 2.82 | .10 | 6.12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | .... | ...... |
| Maximum | .40 | .11 | 7.15 | 8.65 | 9.84 | 12.67 | 17.24 | 11.73 | 9.96 | 5.73 | 2.79 | 1.62 | 36.29 | .... | 43.23 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | .25 | 0 | .02 | 0 | 0 | 0 | 4.49 | .... | 7.22 |
| Mean..... | .02 | .01 | .42 | .82 | 1.42 | 3.27 | 4.68 | 3.56 | 2.92 | 1.14 | .44 | .10 | 18.64 | .... | 18.60 |

[a] Interpolated.

## INTENSITY AND DISTRIBUTION OF RAINFALL.

The magnitude of the flood resulting from a given amount of precipitation is determined largely by the intensity of the rainfall and its distribution through the month. The records of the United States Weather Bureau, supplemented by records from private parties, give the information concerning excessively heavy rainfall at San Diego, Los Angeles, Squirrel Inn, and Campo, which is presented in the following paragraphs:

*San Diego.*—A self-registering rain gage was installed in San Diego in 1893, but was not in operation during the storms of January, 1916, so that the rate of fall is unknown. The total rainfall recorded from January 15–18, inclusive, was 2.90 inches.

Records collected by William A. Edwards, M. D.,[1] give the following maximum records for 24 hours rainfall:

| | Inches. |
|---|---|
| Dec. 3, 1873, 10 p. m. to night of Dec. 4 | 2.52 |
| Nov. 9, 1879, morning to 8.10 p. m. | 2.75 |
| Dec. 27, 1879, 6 a. m. to Dec. 28, 6 a. m. | 2.55 |
| Jan. 12, 1882, 3.50 a. m. to Jan. 13, 3 a. m. | [2]2.49 |

The heavy rain of December 28, 1896, was the maximum recorded to that date on the self-registering gage and fell at the following rates: 1 minute, 0.19 inch; 5 minutes, 0.32 inch; 10 minutes, 0.47 inch; 1 hour, 0.79 inch.

Records in the San Diego office of the United States Weather Bureau show that on March 15, 1905, the rate of fall was as follows: 5 minutes, 0.32 inch; 10 minutes, 0.41 inch; 15 minutes, 0.58 inch; 30 minutes, 0.74 inch; 1 hour, 0.94 inch; 2 hours, 0.95 inch. A rate of 1 inch in an hour has never been recorded at San Diego.

*Los Angeles.*—The heaviest rainfall during January, 1916, began at 1.05 p. m., January 16, and ended at 9.30 a. m., January 18; the total for this period was 5.74 inches. From 3.17 a. m. to 3.29 a. m. the rate was as follows: 5 minutes, 0.20 inch; 10 minutes, 0.42 inch,; 15 minutes, 0.46 inch.[3]

Other heavy rainfalls, occurring in 1889, have been reported by the Los Angeles office of the United States Weather Bureau as follows: From December 11, 8 p. m., to December 12, 8 p. m., total rainfall 4.30 inches. From December 24, 8 p. m., to December 25, 8 p. m., 2.72 inches. The rainfall on December 24, from 9.45 p. m. to 10.45 p. m., is estimated at 1 to 1.25 inches.

*Squirrel Inn.*—The total precipitation from January 14–19, inclusive, at Squirrel Inn, north of San Bernardino, on the south slope of the San Bernardino Mountains, at an elevation of 5,280 feet above sea level, was 27.80 inches, or an average of 4.63 inches for each day. The 24-hour precipitation January 16–17 was 16.81 inches, one of the heaviest for that period of time ever recorded in the United States, and a new record for California.

*Campo.*—A rainfall of the "Sonora" type occurred at Campo August 12, 1891. The total rainfall for this storm, which lasted more than 24 hours, was 16.10 inches, according to Mr. Archibald Campbell, cooperative observer. In a period of about 80 minutes the rainfall was 11.50 inches.

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[1] Reprinted in Littoral California, p. 3, from the Philadelphia Medical Journal, Oct. 11, 1902.

[2] Correct; amount published in Littoral California in error.

[3] Abstracted from United States Weather Bureau Monthly Weather Review, vol. 44, No. 1, p. 57, January, 1916.

In the following table the daily distribution of rainfall during the month of January, 1916, is compared with that of the months of December, 1889, and February and March, 1884, which were the months of previously recorded maximum rainfall:

*Daily precipitation, in inches, for months of maximum rainfall at San Diego and Los Angeles, Cal.*

| Day. | San Diego. | | | | Los Angeles. | | | |
|---|---|---|---|---|---|---|---|---|
| | December, 1889. | January, 1916. | February, 1884. | March, 1884.[a] | December, 1889. | January, 1916. | February, 1884. | March, 1884. |
| 1 | 0.94 | | 0.44 | | 1.11 | 0.60 | 1.61 | |
| 2 | | | .43 | Tr. | .77 | 1.07 | 2.84 | Tr. |
| 3 | .02 | | 1.52 | 0 34 | Tr. | | .45 | 1.78 |
| 4 | .12 | | .65 | .17 | .11 | .17 | .29 | 1.97 |
| 5 | | 0.01 | .34 | .25 | | .20 | .60 | 1.98 |
| 6 | .59 | | .80 | .57 | .06 | | .70 | .88 |
| 7 | .10 | | .16 | .09 | .37 | | .62 | .18 |
| 8 | | | | Tr. | .03 | .41 | | .16 |
| 9 | .52 | .20 | | .79 | .46 | .29 | | 2.67 |
| 10 | | .27 | .37 | .15 | | .17 | .49 | .05 |
| 11 | | | .50 | | .02 | | .07 | |
| 12 | | | .01 | | 4.30 | | Tr. | |
| 13 | .14 | | | | .59 | | | |
| 14 | 1.18 | .53 | .12 | 1.39 | .03 | .38 | .05 | 1.00 |
| 15 | 1.75 | .09 | 1.35 | .35 | .72 | .04 | 2.02 | .12 |
| 16 | .07 | .95 | .96 | | | 1.07 | 1.38 | |
| 17 | | 1.55 | 1.31 | | | 4.16 | 2.18 | .04 |
| 18 | .02 | .31 | .09 | .01 | .16 | .82 | .07 | Tr. |
| 19 | .01 | .80 | | | .01 | .43 | | |
| 20 | Tr. | | | | .01 | | | |
| 21 | .01 | | | | | | | |
| 22 | | | | | 1.11 | | | |
| 23 | 1.13 | | | .26 | 1.61 | .01 | | .05 |
| 24 | .44 | Tr. | | | 1.10 | .11 | | |
| 25 | .53 | .21 | | | 2.72 | .33 | | .10 |
| 26 | .05 | .22 | | .72 | .51 | .33 | | .05 |
| 27 | .03 | 2.19 | | Tr. | | 2.28 | | .51 |
| 28 | Tr. | .06 | | .50 | | | | .75 |
| 29 | | .17 | | .26 | | .43 | | Tr. |
| 30 | | | | .02 | | | | .03 |
| 31 | .06 | | | .36 | | | | .04 |
| Total | 7.71 | 7.56 | 9.05 | 6.23 | 15.80 | 13.30 | 13.37 | 12.36 |

[a] Total for March, 1867, was 7.88 inches, but daily record is not available; March, 1884, was the next highest.

## FLOOD OF JANUARY, 1916.

### CREST DISCHARGE.

The heavy storms of January, 1916, fell on ground already saturated, and the water was therefore rapidly carried into the stream channels. Detailed information concerning the discharge of the streams during these storms is given in the run-off records (pp. 40–78) and is summarized in the following tables, which show the crest discharge of the streams and the total run-off compared with the rainfall.

*Crest discharges, in second-feet, of streams in southern California for January, 1916.*

| Station. | Date. | Time. | Gage height (feet). | Drainage area (square miles). | Discharge. | Run-off per square mile. |
|---|---|---|---|---|---|---|
| Cottonwood Creek at Morena reservoir. | Jan. 27 | 4-6 p. m. |  | 120 | 15,356 | 128 |
| Otay River at Lower Otay reservoir. | ...do... |  |  | 98.6 | [a] 23,500 | 238 |
| Jamul Creek near Otay | ...do... |  |  | 69.8 | 18,100 | 259 |
| Sweetwater River near Descanso. | ...do... |  |  | 43.7 | 9,870 | 226 |
| Sweetwater River near Dehesa | ...do... |  |  | 112 | 24,295 | 217 |
| Sweetwater River at Rudolph ranch. | ...do... |  |  | 135 | 27,530 | 204 |
| Sweetwater River near Jamacho. | ...do... |  |  | 172 | 43,002 | 250 |
| Sweetwater River at Sweetwater reservoir. | ...do... | 4.30-5.30 p. m. |  | 181 | 45,500 | 251 |
| San Diego River at diverting dam. | Jan. 18 | 6 a. m. |  | 102 | 4,710 | 46 |
| Do | Jan. 28 | 6 p. m |  | 102 | 15,800 | 155 |
| San Diego River at Capitan Grande dam site. | Jan. 27 |  |  | 189 | [b] 36,300 | 192 |
| San Diego River near Santee | ...do... |  | 25.1 | 375 | 70,200 | 187 |
| San Diego River at San Diego | ...do... | 7 p. m. |  | 434 | 75,000 | 173 |
| Boulder Creek at Cuyamaca reservoir. | ...do... | 6 p. m |  | 12 | 2,393 | 199 |
| San Vicente Creek at mouth | ...do |  |  | 74.9 | 18,600 | 248 |
| Switzer Canyon at San Diego | ...do... | 7 a. m. |  | 3.55 | 668 | 188 |
| Santa Ysabel Creek near Mesa Grande. | Jan. 17 |  |  | 53.4 | 10,600 | 199 |
| Do | Jan, 27 | Noon | 11.0 | 53.4 | 21,100 | 395 |
| Santa Ysabel Creek near Ramona. | Jan. 17 | 9 p. m |  | 110 | 14,300 | 130 |
| Do | Jan. 27 | 7 p. m |  | 110 | 28,400 | 258 |
| San Dieguito River at Carroll dam site. | ...do... | 1-3 p. m | 21.2 | 299 | 72,100 | 241 |
| Santa Maria Creek near Ramona. | ...do... | 5 p. m | 15.9 | 57.3 | 7,140 | 125 |
| San Luis Rey River near Mesa Grande. | Jan. 17 | 1.45 p. m | 12.8 | 209 | 24,400 | 117 |
| Do | Jan. 27 | 4.30 p. m | 18.0 | 209 | 58,600 | 280 |
| San Luis Rey River near Pala | ...do... |  | 18.1 | 322 | 75,000 | 233 |
| San Luis Rey River at Oceanside. | Jan. 17 |  |  | 565 | 40,000 | 71 |
| Do | Jan. 27 | 9.30 p. m |  | 565 | 95,600 | 169 |
| Santa Ana River near Mentone | Jan. 17 |  |  | 189 | 29,100 | 154 |
| Santa Ana River at San Bernardino. | ...do... |  |  |  | 40,000 |  |
| Lytle Creek at San Bernardino | Jan. 18 | 9.40 a. m |  |  | 16,000 |  |
| San Jacinto River near San Jacinto. |  |  |  | 108 | 30,000 | 278 |
| San Jacinto River near Elsinore | Jan. 28 | 11 a. m. | 19.0 | 717 | 14,000 | 195 |
| South Fork of San Jacinto River at Hemet reservoir. | Jan. 27 | 4 p. m. |  | 65.8 | 9,550 | 145 |
| San Gabriel River near Axusa | Jan. 18 | 7 a. m. | 12.0 | 222 | 40,000 | 180 |
| Los Angeles River at Los Angeles. |  |  |  |  | 7,268 |  |
| Los Angeles River near Dominguez Junction. |  |  |  |  | 31,113 |  |
| Arroyo Seco near Pasadena | Jan. 17 | 9.30 a. m | 9.3 | 16.4 | 8,150 | 192 |
| Arroyo Seco at Los Angeles |  |  |  |  | 6,215 |  |
| Sespe Creek near Sespe | Jan. 17 |  | 18.7 | 216 | 18,600 |  |

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[a] Reported by George Cromwell, city engineer, San Diego, (See Engineering News, vol. 75, No. 15, p. 718.)

[b] Mean of two estimates computed from cross sections and slope data.

*Summary of run-off of streams in southern California for January, 1916.*

| Station. | Period (January). | Drainage area (square miles). | Run-off. | | | Mean rainfall on drainage area January 14 to 30 (inches). |
|---|---|---|---|---|---|---|
| | | | Total in acre-feet. | Depth in inches on drainage area. | Per cent of mean rainfall. | |
| Cottonwood Creek at Morena reservoir | 1 to 31 | 120 | 41,200 | 6.43 | .......... | .......... |
| Sweetwater River at Sweetwater dam | 16 to 31 | 181 | 111,000 | 11.55 | 53 | 21.8 |
| San Diego River at diverting dam | 1 to 31 | 102 | 92,800 | 17.06 | 62 | 27.6 |
| San Diego River at San Diego | 1 to 31 | 434 | 213,000 | 9.19 | 46 | 19.9 |
| Boulder Creek near Julian | 13 to 31 | 12 | 12,300 | 19.22 | .......... | .......... |
| Santa Ysabel Creek near Mesa Grande | 1 to 31 | 53.4 | 66,400 | 23.29 | 77 | 30.3 |
| Santa Ysabel Creek near Ramona | 1 to 31 | 110 | 104,000 | 17.75 | 69 | 25.8 |
| San Dieguito River near Bernardo | 1 to 31 | 299 | 257,000 | 16.14 | 68 | 23.6 |
| Santa Maria Creek near Ramona | 1 to 31 | 57.3 | 33,500 | 10.96 | 52 | 21.2 |
| San Luis Rey River near Mesa Grande | 1 to 31 | 209 | 141,000 | 12.68 | 51 | 24.9 |
| San Luis Rey River near Nellie | 1 to 31 | 240 | 165,000 | 12.91 | 51 | 25.4 |
| San Luis Rey River at Pala | 1 to 31 | 322 | 201,000 | 11.76 | 46 | 25.7 |
| San Luis Rey River at Bonsall | 1 to 31 | 465 | 257,000 | 10.36 | 43 | 24.3 |
| San Luis Rey River at Oceanside | 16 to 31 | 565 | 269,000 | 8.92 | 39 | 22.6 |
| South Fork of San Jacinto River at Hemet reservoir | 14 to 31 | 65.8 | 29,100 | 8.30 | .......... | .......... |
| San Gabriel River near Azusa | 1 to 31 | 222 | 148,000 | 12.57 | .......... | .......... |

## CONDITION OF RESERVOIRS DURING FLOOD.

### MORENA RESERVOIR.

The Morena reservoir, on Cottonwood Creek 8½ miles upstream from the Barrett dam, has a capacity of 46,000 acre-feet. It forms a part of the municipal water-supply system of San Diego.[1]

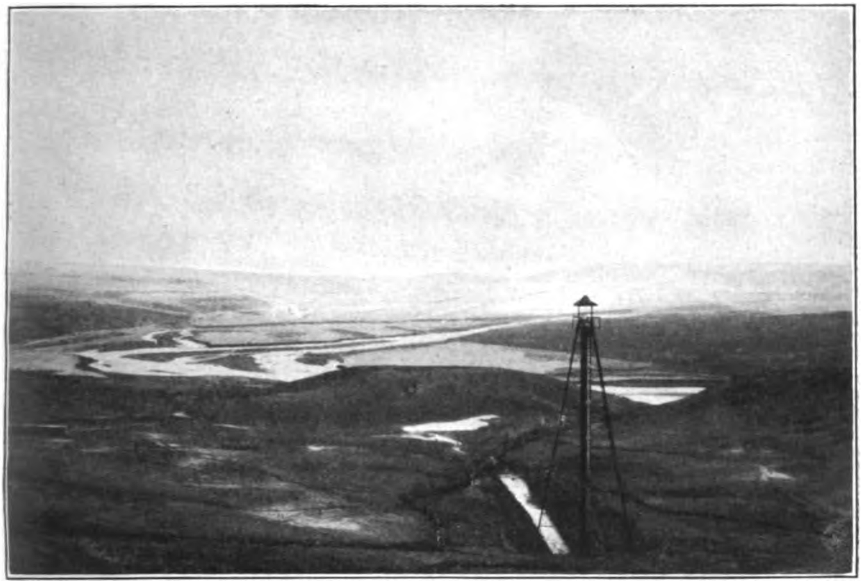
The following is a description[2] of the flood of January, 1916, at this reservoir:

> The flood brought into the reservoir a large quantity of débris which accumulated in front of the racks that protect the radial gates, and so choked the flow that when the reservoir level was 3 feet above the spillway level the flow actually passing over the spillway beneath the open gates was only 3 inches deep. Under these conditions the water rose within 18 inches of the parapet crest and waves actually carried débris over the top.
>
> Two effects of this pressure are apparent. A downstream movement of the upper face of the dam which showed in the alignment of the parapet as about 2 or 3 inches at the center of the structure, and a settlement of the top of the rock fill amounting to 2 or 3 inches. The amount of leakage could not be observed, but George Cromwell, city engineer of San Diego, who was at the dam during the high water, affirmed that he believed such leakage as there was came through the face of the structure and not around the ends or from beneath. Leakage some time prior to recent storms amounted to 1,500,000 gallons per day.
>
> After going down to the bottom of the intake tower during the height of the flood, Mr. Cromwell reported that structure was standing the pressure well, only slight seepage appearing. The intake gates were all in working order and all were left open to lower the reservoir level as much as possible. The débris was being removed by as large a force of men as could be readily assembled. Orders to lower the reservoir 3 feet below the spillway level by means of the intake gates were left at the dam.

---

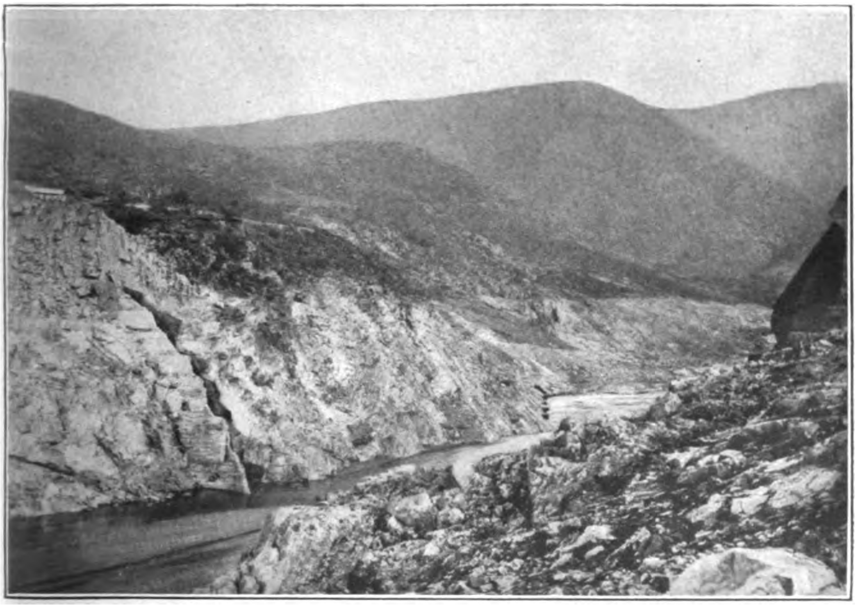
[1] O'Shaughnessy, M. M., Construction of the Morena rock-fill dam, San Diego County, Cal.: Am. Soc. Civil Eng. Trans., vol. 75, p. 27, 1913.

[2] Eng. Record, vol. 73, No. 7, p. 228, February 12, 1916.



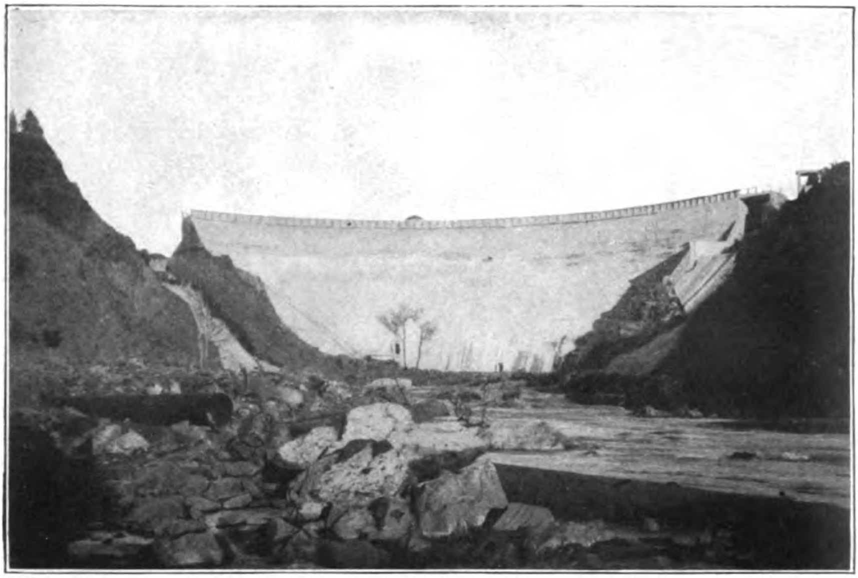
*A*. VIEW UP LOWER OTAY RESERVOIR, AFTER FAILURE OF DAM.

Reservoir gage in foreground.

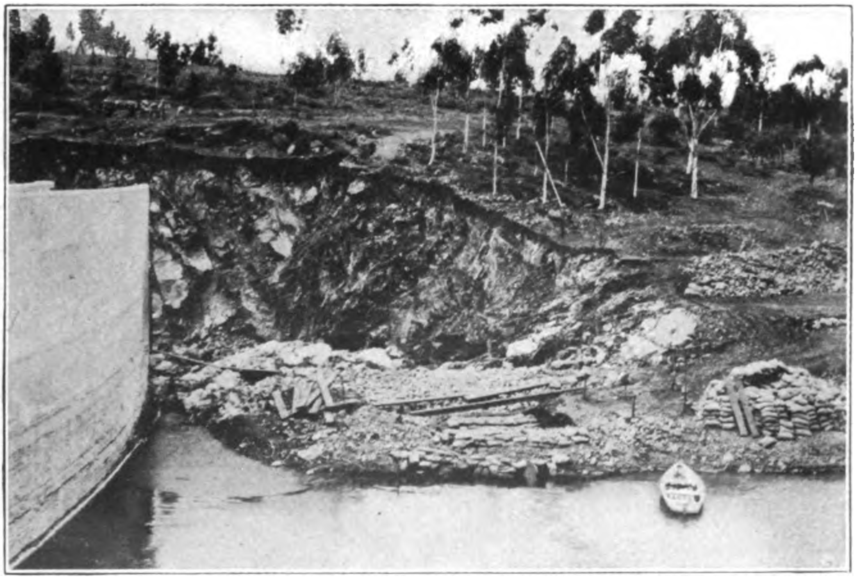


*B*. VIEW DOWNSTREAM AT SITE OF LOWER OTAY DAM, AFTER FAILURE.

Spillway at extreme left



*A.* SWEETWATER DAM, AFTER FLOOD OF JANUARY, 1916.



*B.* BREAK AT RIGHT END OF SWEETWATER DAM, AFTER FLOOD OF JANUARY, 1916.

### LOWER OTAY RESERVOIR.

Two reservoirs known as Upper and Lower Otay have been constructed as a part of the water-supply system for the city of San Diego. Upper Otay is at the lower end of Procter Valley and Lower Otay[1] is on the main stream directly south. The capacity of the former is about 3,300 acre-feet; that of the latter about 40,000. Lower Otay dam was overtopped by the flood on January 27, 1916, and destroyed.

The following is a description of the failure of Lower Otay dam by Roy A. Silent:[2]

> The rain on January 27 was extremely heavy, and by noon the water had risen so high that Mr. Weuste, in charge at the dam, deemed it advisable to open the outlet gate. This failed to check the rise, and it was realized that the dam would probably be overtopped before evening. Men were accordingly dispatched to warn residents in the valley to move to higher ground. Word to this effect was also sent out from the telephone exchange at National City. Most of the inhabitants took advantage of this warning.
>
> At 4.45 p. m. the water had reached the top of the dam and had seeped through and filled the boxes that were sunk in the top to allow an examination of the steel core. Water began running down the lower face on the east side of the dam at approximately 4.50 p. m. About this time several spouts or small streams of water appeared on the lower face of the dam, in one instance loosening a large bowlder which rolled down to the bottom. From this time on, the destruction was very rapid. The lower face of the fill quickly melted away, thus removing the support from the core wall. At 5.05 p. m. the tension was so great that the steel diaphragm tore from the top at the center, and the dam opened outward like a pair of gates. The released water rushed through and filled the canyon to a point approximately 20 feet below the top of the dam. It required 2½ hours for the reservoir to empty.
>
> A huge wall of water, variously described as from 6 to 20 feet high, rushed down the valley, covering the distance from the dam site to Palm City, about 10 miles, in 48 minutes, carrying all before it. * * *
>
> A thorough examination of the dam site was made on January 31 and February 1. Practically all the fill was washed completely away. The steel core was deposited in varying-sized sections along the valley, a large part being found at Palm City, 10 miles below the dam. The core wall had torn itself loose from both of the side walls, the foundations remaining intact. * * *
>
> Three-quarters of a mile below where the dam had stood a piece of the diaphragm was observed, to which the angle iron forming the bottom of the steel plate was riveted, showing that the extreme bottom had been torn loose. On the west side, behind the remaining core wall, was a small part of the fill, composed of rock of small sizes, none of which was over 1½ feet in diameter and grading from that size to coarse gravel. If this may be considered a fair sample of the remainder of the fill, it is easy to understand its melting away as rapidly as described.
>
> The canyon below the dam, prior to the failure, was considerably restricted and filled with large boulders. The action of the water removed all the loose rock and thoroughly stripped to bedrock both sides of the canyon as high as the water reached, the line of demarcation being clearly defined. The stripping was done in a most thorough manner, no particle of soil remaining in any of the niches or crevasses. This area was heavily wooded with brush. [See Pl. II, *B*.]

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[1] Schuyler, J. D., Reservoirs for irrigation: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 4, pp. 637-640, 1897.

[2] Eng. News, vol. 75, No. 7, pp. 334-336, February 17, 1916.

An interesting feature was observed in that for half a mile below the dam in practically every pocket or niche in the rock was to be found a rivet head. An examination of the remaining parts of the steel core showed it to be in a perfect state of preservation, no rust or corrosion being noticeable. The destruction of the plate for the most part had taken place along the riveted seams, though one or two cases in which the sheets had torn were observed.

Other accounts of the failure have also been published.[1]

### SWEETWATER RESERVOIR.

The celebrated Sweetwater masonry dam is on Sweetwater River about 8 miles above its mouth at an elevation of 145 feet.[2]

The following description of the breaks in Sweetwater reservoir was prepared from information supplied by Mr. J. F. Covert, chief engineer, Sweetwater Water Co.:[3]

On January 27 the flow into the reservoir exceeded the combined capacity of spillway and blow-off valves, and the level behind the dam raised until the parapet was overtopped at 2.20 p. m. At 4.30 p. m the flow over the parapet had increased to a depth of 3.5 feet, and the 50-foot length of earth-fill dike at the north end of the structure was overtopped. The water washed away this fill, broke the concrete-core wall, and cut a by-pass around the dam through the bedrock foundation. The break is about 75 feet wide, with a maximum depth of 30 feet below the level of parapet. [See Pl. III.]

This break was made by degrees, no water appearing below the dike until it was actually overtopped, and the cutting into the foundation was gradual. At 7 p. m. the reservoir level was lowered only 0.3 foot. Water flowed over the parapet about seven hours after the break occurred, it is believed, which would mean that the flood continued to overtop the dam for about nine hours.

An earthen dike 650 feet long stood some distance from the dam, where a low point in the ridge occurred. This dike had a puddled-clay core and was 23 feet high at its mid-point. At 3.50 p. m. on the day of the flood peak the water level reached the top of this dike and began to spill over the downstream slope. This melted as the water continued to rise, and when the flood subsided the dike had been swept out cleanly except for about 10 feet of its length. The material on which the dike stood was eroded by the outpouring water to such an extent that the reservoir rim at this point is now 15 feet below the spillway level.

### CUYAMACA RESERVOIR.

Cuyamaca reservoir is formed by an earthen dam on Boulder Creek, a tributary of San Diego River. The capacity given by a 35-foot dam is 11,400 acre-feet.[4]

The effect of the flood on this reservoir has been described as follows:[5]

The impending danger of the recent flood was realized in time to draw down the Cuyamaca reservoir considerably. In fact, the amount drawn off by the blow-off valve through the dam was about 1,000,000,000 gallons. The peak of the flood brought the reservoir level up to within 14 inches of the crest of the dam, with both spillways flowing over 4 feet deep. A few washouts on the conduit constituted the only damage suffered by this system, which includes, in addition to the Cuyamaca dam, three smaller reservoirs on tributaries of the San Diego River.

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[1] Eng. News, vol. 75, No. 5, pp. 236-239, Feb. 3, 1916; Eng. Record, vol. 73, No. 7, p. 226, Feb. 12, 1916.

[2] Schuyler, J. D., Reservoirs for irrigation: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 4, pp. 669-682, 1897; also details of design and last increase in height, in Eng. Record, Sept. 2, 1911, p. 264.

[3] Eng. Record, vol. 73, No. 7, p. 225, Feb. 12, 1916.

[4] Schuyler, J. D., Reservoirs for irrigation: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 4, pp. 698-700, 1897.

[5] Eng. Record, vol. 73, No. 7, p. 228, Feb. 12, 1916.

## DAMAGE DUE TO FLOOD.

An inventory of the damage in Los Angeles, San Bernardino, Riverside, Orange, and San Diego counties, believed to be practically complete except for minor losses, is given in the following pages. Every effort was made to obtain the best information available, and all public officials, engineers, and others to whom requests were made for estimates regarding losses in their departments or business gave hearty cooperation. A number of the statements were prepared within a few months after the storms, and hence were based upon estimated costs rather than actual expenditures. The loss of life was determined from reports obtained from the coroners of each county. The total direct damage is estimated at about $10,000,000. This estimate is based on the best available information, which is summarized in the following table:

*Summary of flood damage in southern California January, 1916.*

| Character of damage. | San Diego County. | Orange County. | Riverside County. | San Bernardino County. | Los Angeles County. | Total. |
|---|---|---|---|---|---|---|
| Lives lost | 22 | 4 | 0 | 2 | 0 | 28 |
| Agricultural lands | $1,500,000 | $350,000 | $350,000 | $150,000 | $500,000 | $2,850,000 |
| Municipal | 72,850. | 32,000 | 50,000 | | 19,000 | 173,850 |
| Water supply | 1,225,500 | 57,000 | 67,450 | | | 1,349,950 |
| Power plants | | | | 94,565 | 1,600 | 96,165 |
| Railroads [a] | | | | | | 1,795,201 |
| Highways and bridges | 652,350 | 81,500 | 128,600 | 155,130 | 254,638 | 1,272,218 |
| Telegraph and telephone lines [a] | | | | | | 126,100 |
| Miscellaneous | 231,427 | | 9,000 | 200 | | 240,627 |

[a] The damage to railroads and telegraph and telephone lines was not reported in such shape that it could be segregated by counties.

### LOSS OF LIFE.

Twenty-two persons were drowned in San Diego County. Most of them were living in Otay Valley and were swept away by the flood wave which was released from Lower Otay reservoir when the dam failed. A few lives were lost in Mission Valley, on San Luis Rey River. In Orange County four persons were drowned; two were in a cottage which floated down Santa Ana River, one was swept from the highway by the force of the water, and the other was in a wagon which was overturned. In San Bernardino County two men were drowned. No deaths were reported in Riverside and Los Angeles counties.

### AGRICULTURAL LANDS.

*San Diego County.*—The valley lands along Tia Juana, Otay, Sweetwater, San Diego, San Dieguito, and San Luis Rey rivers were flooded. A large part of the bottom land was either cut up by new stream channels or covered with a large amount of sand, brush, and trees. A part of the land in each valley was quickly cleared, but there is a large area reclaimable only by large expenditures of time and money, and there are other large areas whose agricultural value was almost completely destroyed. An example is afforded by a tract of land in Otay Valley formerly used as a truck garden and valued at $1,000 per acre; after the flood 11 acres of this land were sold at a foreclosure sale for $100. The total damage to farm land was approximately $1,500,000. (See Pls. IV, V, VI.)

*Orange County.*—The total damage to agricultural lands in Orange County was approximately $350,000.

*Riverside County.*—The damage to lands in Riverside County is believed to have been at least $350,000.

*San Bernardino County.*—The damage to orange groves in San Bernardino County was considerable, and a number of the alfalfa ranches were practically ruined. The total damage was about $150,000.

*Los Angeles County.*—The principal injury to lands in Los Angeles County resulted from deposits of silt and the cutting of new stream channels. The damage was approximately $500,000.

### MUNICIPAL PROPERTY.

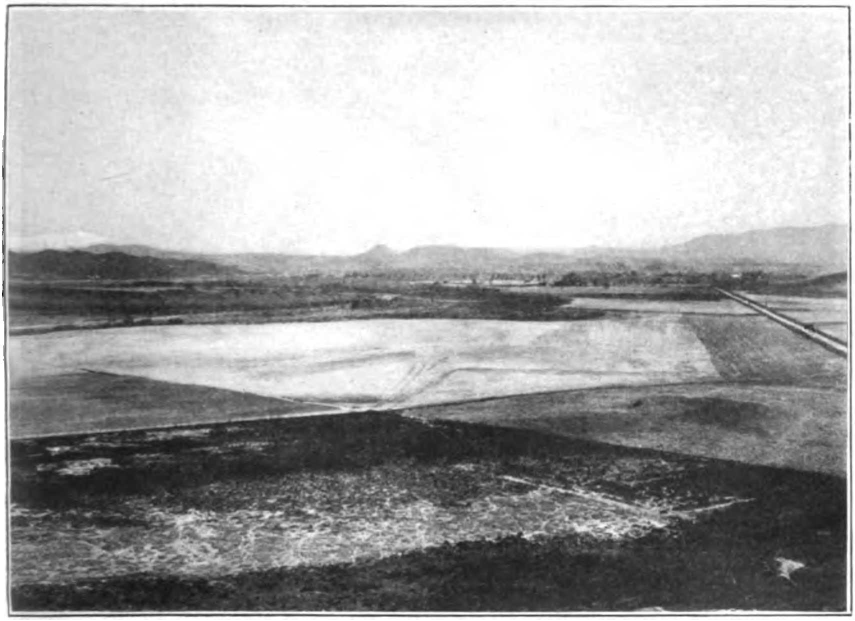
*San Diego.*—The 300-foot concrete arch bridge across San Diego River at Old Town was wrecked (see Pl. VII, *A*) and five other bridges and numerous culverts were destroyed or seriously injured. The streets and roads in various parts of the city were washed or covered with débris. An approximate estimate of the total damage was $72,850.

*San Bernardino.*—The water main and several small pipe lines were washed out; two bridges were completely destroyed; and several sidewalks, curbs, and streets were damaged or destroyed. In addition several houses were washed away. The total damage was approximately $32,000.

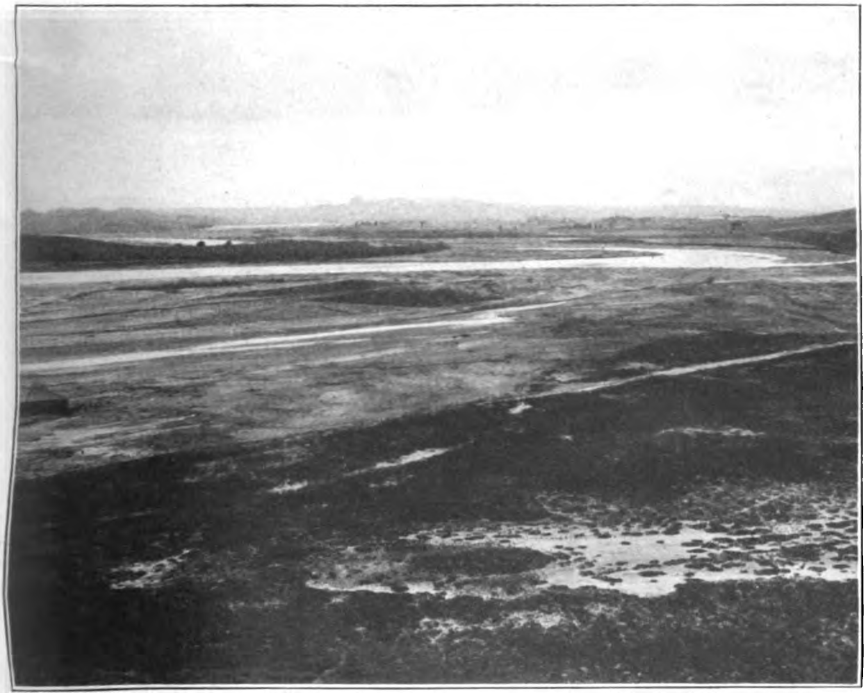
*San Jacinto.*—The damage to the water-supply systems, streets, and private property within the city limits was approximately $50,000.

*Pomona.*—The principal damage resulted from washes and fills in the streets. The estimated cost of repairs was $15,000.

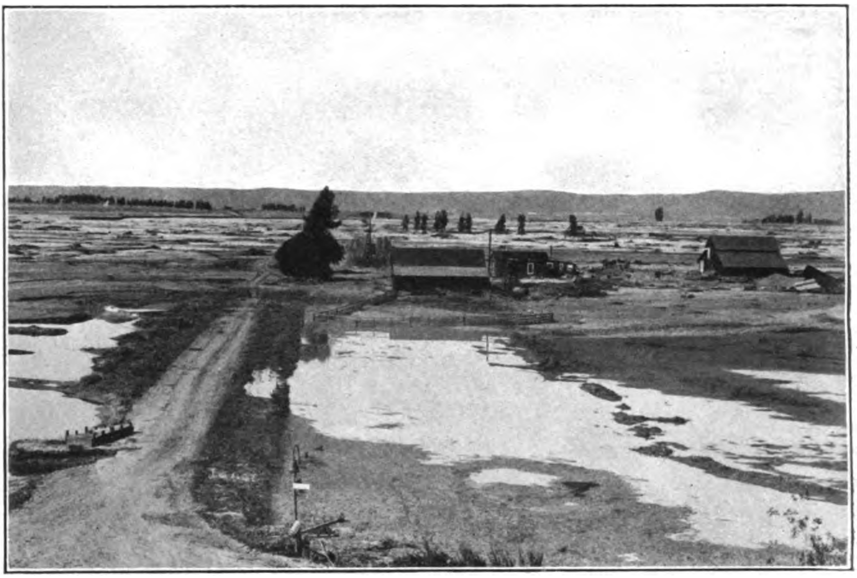
*Pasadena.*—The damage to street improvements amounted to about $1,000, but otherwise there was no loss within the city.



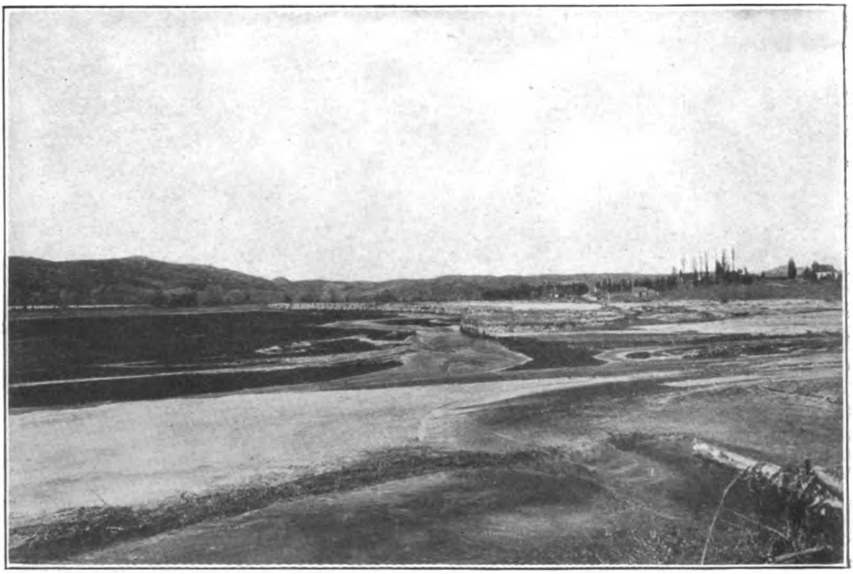
*A.* VIEW UP MISSION VALLEY, SAN LUIS REY RIVER, IN 1915.



*B.* VIEW UP MISSION VALLEY, SAN LUIS REY RIVER, FEBRUARY 21, 1916.



*A*. VIEW ACROSS MISSION VALLEY, SAN LUIS REY RIVER, AT D. JONES'S RANCH, AFTER FLOOD OF JANUARY, 1916



*B*. VIEW UP SAN LUIS REY RIVER AT JUNCTION WITH MOOSA CANYON CREEK, AFTER FLOOD OF JANUARY, 1916.

*Los Angeles.*—A few unimportant wooden bridges were washed out and new channels formed. The damage was reparable at a cost of $3,000, which includes the removal of débris that collected at pile bents of several bridges.

### WATER SUPPLY.

*City of San Diego.*—The failure of Lower Otay dam and the loss of the stored water was the most important damage (Pl. II). About 18 miles of Dulzura conduit was filled with débris and 2,800 feet of flume and concrete-lined section was destroyed. The road up Cottonwood Creek to Morena was seriously washed and blocked by slides. The washout of the pipe line across Sweetwater Valley prevented the delivery of water from this system. The loss of wells, pumps, and collecting pipe lines at the Mission Valley plant shut off the supply from this source. The total estimated damage was $897,500.

*Sweetwater Water Co.*—The north abutment of Sweetwater dam, consisting of a concrete-paved earth fill with reinforced concrete core wall, was overtopped to a depth of 3.64 feet and destroyed. The released water eroded the bedrock foundation at this end of the dam, leaving an opening about 50 feet deep and 100 feet long. Slight damages to the south abutment and spillway did not reduce the capacity of the reservoir. An earth dike, 650 feet long and 23 feet high, on the south side of the reservoir, about a mile above the dam, was overtopped and completely washed out. These breaks reduced the capacity of the reservoir from 35,000 acre-feet to 12,000 acre-feet. Temporary repairs increased the reservoir capacity to 25,000 acre-feet. In Sweetwater Valley 15,140 feet of pipe lines were washed out and other sections shifted or filled with sand. An approximate estimate of the cost of necessary repairs and enlarged spillway was $200,000. (See Pl. III, p. 25.)

*Cuyamaca Water Co.*—The principal damage was the loss of flume along upper San Diego River. The estimated cost of repairs to flume and pumping plants was $60,000.

*South Coast Land Co.*—The water supply for the town of Del Mar is obtained from wells on Santa Fe ranch in San Dieguito Valley, 6 miles above the mouth of the river. This pipe line was practically washed out. The new pipe line, completed about the middle of May, follows a new course along the foot hills.

The high water on January 17 did not damage the steam pumping plant in San Luis Rey Valley, but that of January 27 completely wrecked this plant and 2,000 feet of 16-inch pipe. Only one small section of the concrete building remained above the sand after the flood. The boilers were found 50 feet from their original position and covered with 30 feet of sand. The total damage to property of this company was about $60,000.

*Escondido Mutual Water Co.*—The principal damage was caused by slides which either filled or destroyed sections of the canal. About 8,000 yards of rock and earth were removed from the canal. Repairs were completed April 18 at a cost of about $8,000.

*Temescal Water Co.*—The main pipe lines and ditches were but slightly damaged. The loss on the tributary lines was much greater. In Mahew Canyon, 1,100 feet of 8-inch pipe was washed out. The dam at Lee Lake in Temescal Canyon failed, and a mile or more of 18-inch pipe line below the dam was washed out. The total damage was about $13,750.

*Riverside Water Co.*—The damage reported, including the rebuilding of the headworks, was approximately $10,000.

*Lake Hemet Water Co.*—The damage to headworks, canal, and pipe lines was about $43,700.

*Anaheim Union Water Co.*—The concrete head gate was undermined and washed out, several thousand feet of main canal were seriously injured, and considerable damage was done to the distribution system and roads. The total damage was about $57,000.[1]

### POWER PLANTS.

*Pacific Light & Power Corporation.*—The Mentone plant on Santa Ana River was stopped on January 17 and started April 1. The masonry diversion dam, two masonry sand boxes, and 400 feet of concrete-lined canal were wrecked. A corner of the power plant was undermined, but the building was uninjured. The semicircular wood stave flume crossing the river from power house to North Fork ditch was completely carried away. The road up the canyon to the intake was practically all washed out. The transmission line was damaged but little, as it was on high ground. The total cost of repairs to this plant was $25,000.

The intake and 200 feet of pipe line were washed out at the Sierra plant on San Antonio Creek, as was also the road up San Antonio Canyon. The total cost of repairs was $1,600.

*Southern California Edison Co.*—The headworks and flume No. 8 at Santa Ana River plant No. 1 were destroyed, the buildings were seriously damaged, and a large amount of débris was deposited in the tailrace and on the floor of the power house. The siphon across Santa Ana River from the tailrace of plant No. 1 to intake of plant No. 2 collapsed. Plant No. 2 was not otherwise damaged, although a severe wash threatened to undermine the power house. The flume across the wash between Mill Creek power houses Nos. 2 and 3 was completely wrecked, and the pressure pipe line was washed out in several places. There were also minor damages to the headworks and various sections of flume on the canal lines. The intake for the

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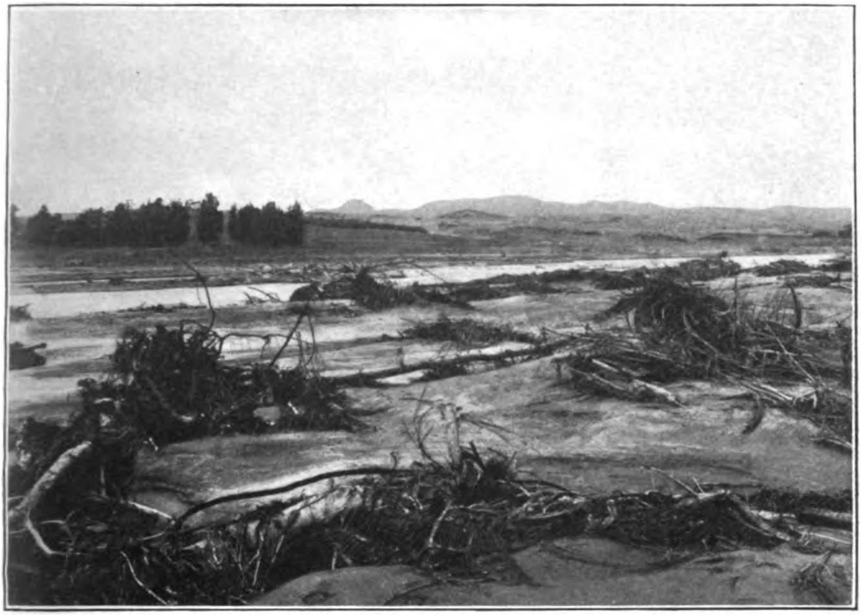
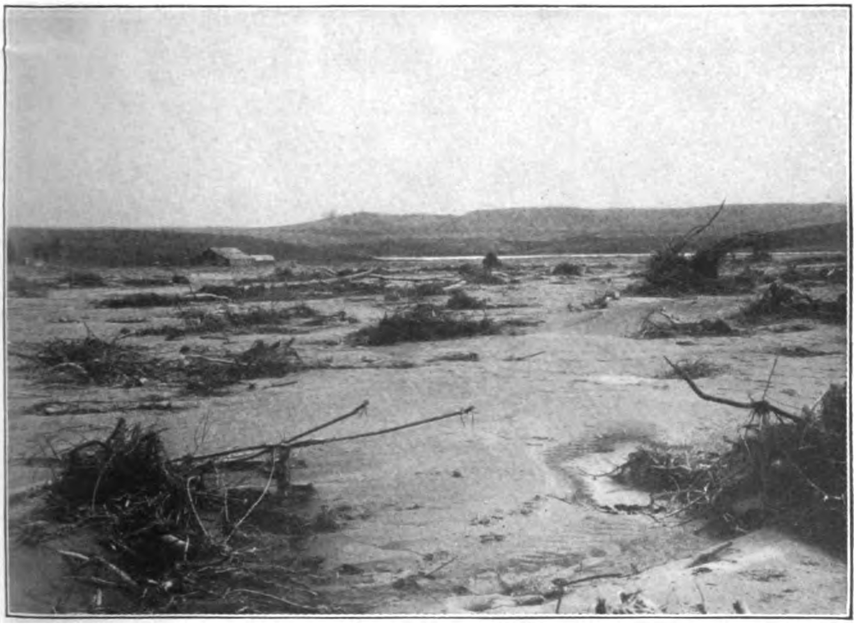
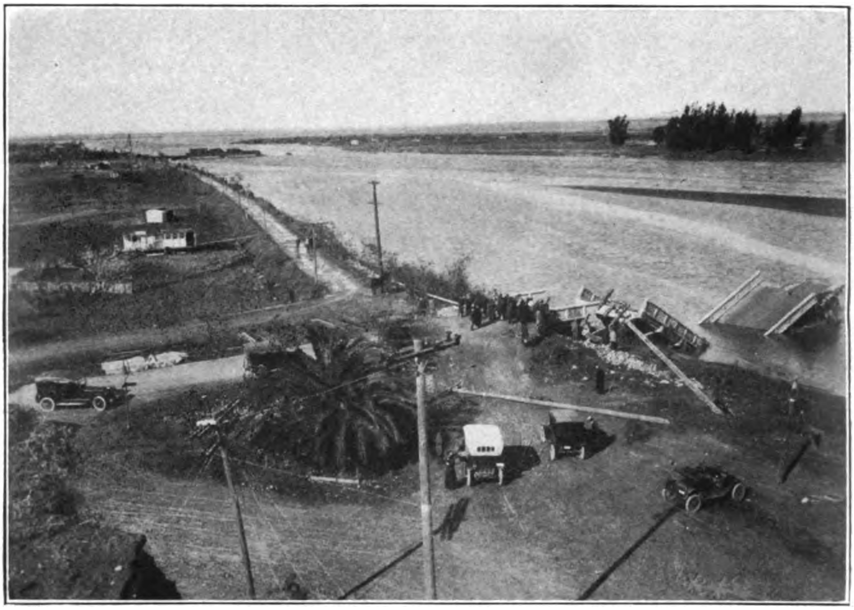
[1] From report to directors and stockholders on construction work for 1916.



*A.* WINSTON RANCH, MISSION VALLEY, SAN LUIS REY RIVER, FEBRUARY 21, 1916.

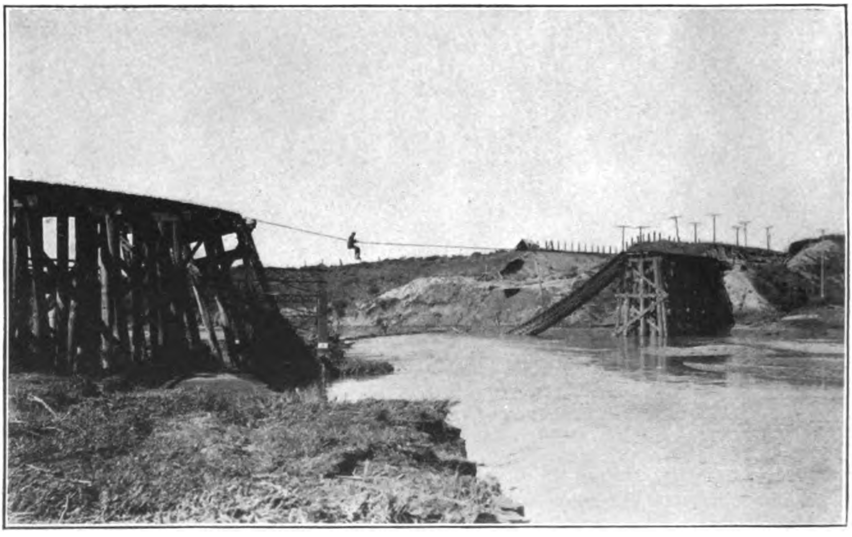


*B.* CANFIELD RANCH, NEAR BONSALL, SAN LUIS REY RIVER, FEBRUARY 21, 1916.



*A.* SAN DIEGO RIVER AT SAN DIEGO, AFTER FLOOD OF JANUARY, 1916.

Showing damage to county and Atchison, Topeka & Santa Fe Railway bridges.



*B.* SANTA MARGARITA RIVER NEAR MOUTH, AFTER FLOOD OF JANUARY, 1916.

Showing damage to State highway and Atchison, Topeka & Santa Fe Railway bridges.

Lytle Creek plant was seriously injured and the tailrace siphon was destroyed. Many of the wooden poles in the transmission line down Santa Ana Canyon were washed out. Several towers were also undermined along lower Santa Ana, San Gabriel, and Los Angeles rivers. The damage to the entire system was approximately $56,200.

*Southern Sierras Power Co.*—The damage to the system of the Southern Sierras Power Co. was principally confined to the transmission lines. Temporary repairs were completed in three days. The estimated damage was $13,365.

### RAILROADS.

*Atchison, Topeka & Santa Fe Railway Co.*—The greatest damage to property belonging to the Santa Fe Railway Co. was on the line between Los Angeles and San Diego, where several miles of track, including many bridges and trestles, were entirely washed out. On the Fallbrook branch, which is 18 miles long, 4,500 feet of bridges was lost, 6½ miles of track disappeared, 4½ miles was washed off roadbed, and 4½ miles covered with sand. The damage in the other districts was less severe. Traffic was restored on the double track between San Bernardino and Barstow February 2; between San Bernardino and Redlands February 3; and on Temecula branch February 29. The line between Los Angeles and San Diego, including Escondido branch, was restored to traffic February 19. An approximate estimate of the total damage, made shortly after the flood, was $1,000,000. This estimate was based simply on replacing the track and roadbed to its original position and did not take into account any work that will be necessary to protect the track from future floods. (See Pls. VII and VIII, *A*.)

*Southern Pacific Co.*—The damage to the Southern Pacific system was estimated at $216,000. The first through eastbound passenger train after the flood left Los Angeles January 30, was held at Colton until 6.20 p. m. the following night and arrived at Yuma, Ariz., at 7.59 p. m. February 1. The first westbound passenger train after the flood reached Los Angeles at 1 a. m. February 1. The Tustin branch was opened to traffic February 7. The coast and valley lines north of Los Angeles were not seriously damaged.

*Los Angeles & Salt Lake Railroad Co.*—The excessive run-off began to weaken the structures on the Salt Lake line on January 17. In the Pasadena district traffic was delayed until January 21; in the first district—Los Angeles to Riverside—until January 22; and in the San Pedro district until January 28. Several bridges were injured and track was badly washed in many places. The total estimated cost of the repairs necessary to restore the lines in Los Angeles and Riverside counties was $50,000.

*Pacific Electric Railway Co.*—This company, in addition to its city lines, controls an extensive suburban system extending in all directions from Los Angeles. It serves parts of Los Angeles, San Bernardino, Riverside, and Orange counties. There were many interruptions to traffic during the flood period caused by washouts, flooded tracks, slides, and injury to bridges. Through traffic to Los Angeles over the Riverside-Rialto line, stopped by the loss of the Santa Ana bridge on January 17, was not completely resumed until March 3. Through service on the San Pedro-Los Angeles line was resumed January 31. The Newport line was not restored at Signal Hill until April 5 and was then operated with a single track until May 19. The total damage to property of this company was about $141,575.

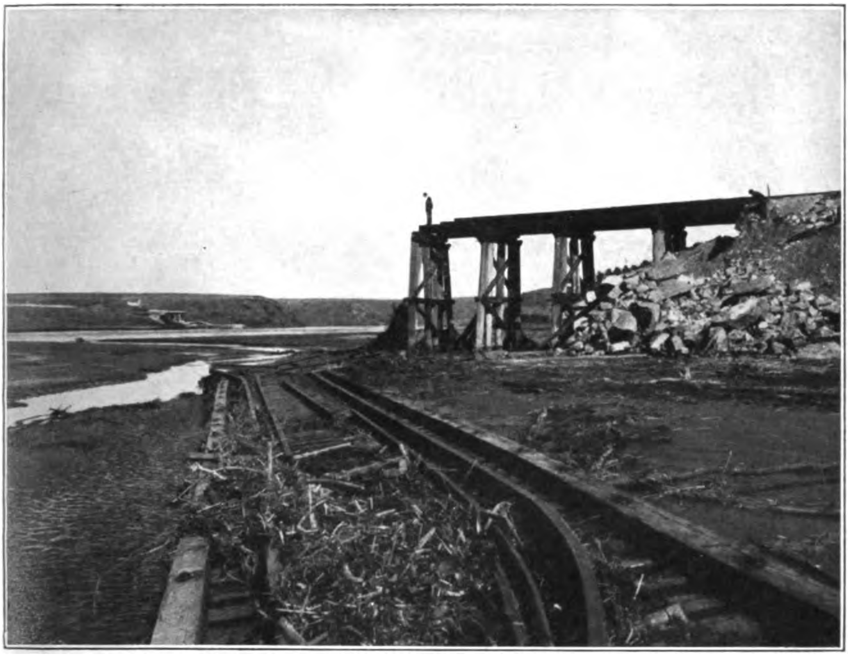
*San Diego & Southeastern Railway Co.*—The total trackage of this company, including sidings and spurs, was 92.99 miles. The flood washed out 19.65 miles, or more than 21 per cent of the total track. The damage to the eastern division was caused principally by the floods on San Vicente Creek and San Diego River. All tracks in the Sweetwater Valley were washed out by the water released from Sweetwater reservoir after the break in the upper section of the dam. The failure of the Lower Otay dam resulted in the loss of all tracks in Otay Valley. The total estimated damage in the eastern and southern divisions was $318,626, including $30,000 for rolling stock.

*Los Angeles & San Diego Beach Railway Co.*—This road is within the city limits of San Diego. The damage included a trestle bridge 872 feet long and 2,700 yards of fill. The cost of the repair work was $14,000. Service was partly interrupted from January 11 to February 29, and wholly from January 29 to February 11.

*San Diego & Arizona Railway Co.*—The damage to this road resulted from the failure of the Lower Otay dam and the break in the Sweetwater dam. The cost of replacement and repairs to grade, track, culverts, and bridges was estimated at approximately $55,000.

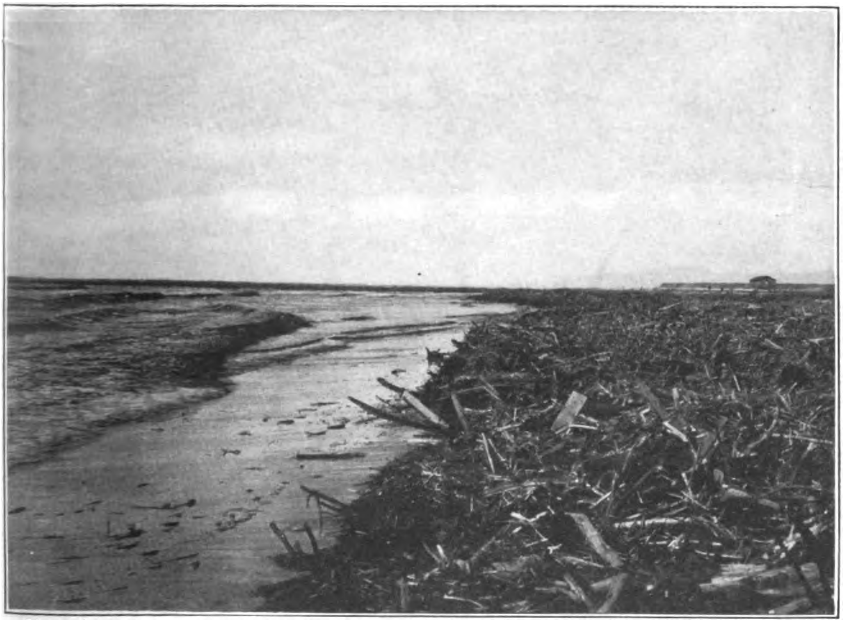
### HIGHWAYS AND BRIDGES.

*San Diego County.*—Practically all important bridges in the county were washed out or became useless on account of changes in the channels of the streams. (See Pl. IX.) All roads were badly washed and some sections will require relocation when permanent repairs are made. Slides were numerous in the mountain districts, and all travel stopped until temporary repairs could be made. The estimated damage to county highways was $370,000 and to bridges, $225,000. The State highway to San Diego was closed until the middle of March. Several bridges or their approaches, including those across Santa Margarita Creek (Pl. VII, *B*), San Luis Rey River (700-foot reinforced-concrete arch bridge, Pl. VIII, *A*), and San Dieguito River,

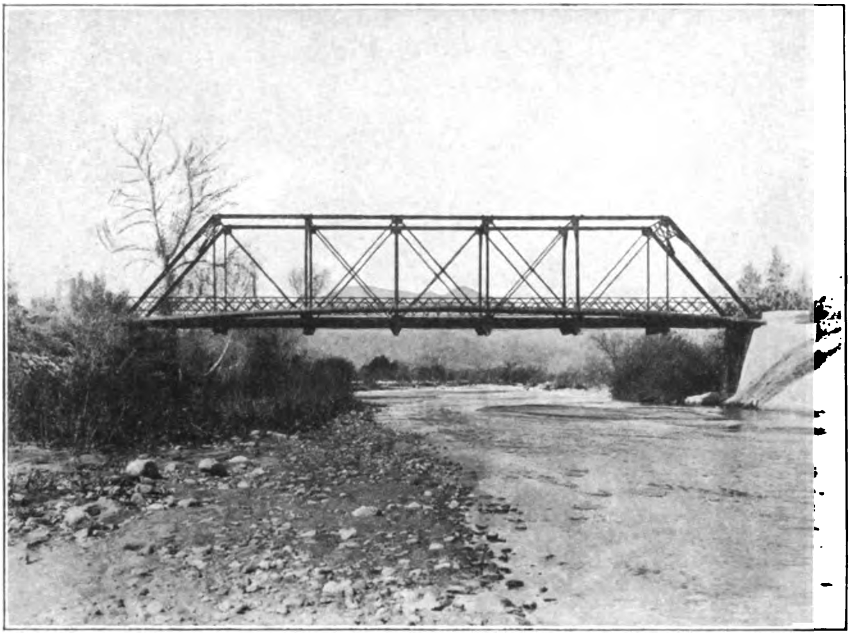


*A.* VIEW UP SAN LUIS REY RIVER FROM MOUTH, AFTER FLOOD OF JANUARY, 1916.

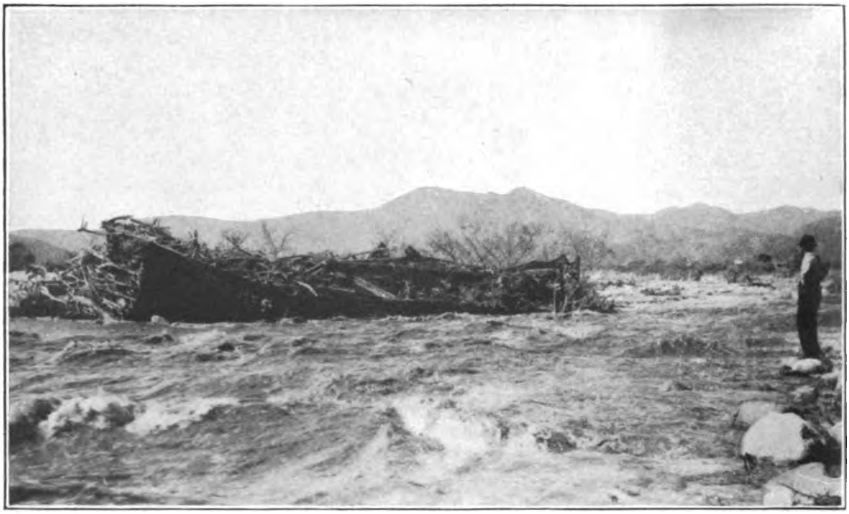
Showing damage to Atchison, Topeka & Santa Fe Railway and State highway bridges.



*B.* DÉBRIS ON BEACH AT OCEANSIDE AND DELTA BUILT UP BY SAN LUIS REY RIVER, AFTER FLOOD OF JANUARY, 1916.



*A.* HIGHWAY BRIDGE ACROSS SAN LUIS REY RIVER AT PALA, BEFORE FLOOD OF JANUARY, 1916.



*B.* WRECK OF HIGHWAY BRIDGE ACROSS SAN LUIS REY RIVER AT PALA, AFTER FLOOD OF JANUARY, 1916.

were destroyed. Except for slight damage to shoulders and a few culverts, the concrete roadway was not injured. The damage to State highway, including repairs made during the storms, was about $57,350.

*Orange County.*—Almost the entire mileage of mountain roads will have to be rebuilt, as the grades were badly washed or buried by slides. The other graded and oiled roads were slightly damaged by deposits of débris and occasional washouts. The injury caused by undermining and shoulder cutting of paved highway was nominal. The loss of bridges was not considered, as they were old wooden structures which should have been replaced. The total damage was about $45,000. In addition, the State highway loss was approximately $36,500, including repairs made during the storms.

*Riverside County.*—The damage to 15 bridges, including 4 across Santa Ana River, was about $78,100. Several roads were badly washed out and the loss was approximately $32,000. The injury to State highway, including repairs made during the storms, was about $18,500.

*San Bernardino County.*—Nearly 40 bridges, including 3 across Santa Ana River, were washed out or damaged. The cost of replacement and repairs was about $67,524. The roads in every section of the county were seriously damaged. On Turner Avenue, Cucamonga, the entire street was washed out from 4 to 12 feet in depth for a distance of 4½ miles. Cajon and Mill Creek roads were badly washed and required extensive repairs. The damage to roads and culverts was about $80,656. The injury to State highways, including repairs made during the storms, was about $6,950.

*Los Angeles County.*—The estimated damage to roads and bridges was $228,388. In addition, the State highway loss, including repairs made during the storms, was about $26,250. A slide in section B, route 4, made it necessary to relocate the road.

### TELEGRAPH AND TELEPHONE LINES.

*Western Union Telegraph Co.*—Practically all through lines were damaged by washouts at the principal stream crossings. Service was interrupted four days at the San Gabriel crossing, and the San Diego line closed for approximately a week. The total damage was about $23,500.

*Postal Telegraph-Cable Co.*—The main lines to San Francisco, San Diego, and the East were damaged and service interrupted. The Los Angeles-San Diego line was washed out at practically every river crossing and at numerous other points. Service between Los Angeles and San Diego was stopped for nearly a week, and the other lines were closed from one to three days. The total cost of repairs was about $5,000.

*Pacific Telephone & Telegraph Co.*—The cost of reconstructing exchange lines, various sections of toll lines, and river crossings, either destroyed or rendered unsafe, was $97,600. Service, particularly over toll lines, was more or less interrupted for a period of approximately 606 hours.

### MISCELLANEOUS DAMAGES.

*San Diego Consolidated Gas & Electric Co.*—The transmission lines and distribution system along San Diego River were washed out from El Monte to False Bay. There were also extensive washouts along Sweetwater River at Jamacho and from Sweetwater dam to San Diego Bay, on Otay River from Otay dam to San Diego Bay, and along Tia Juana River from Tia Juana to the Pacific Ocean. The principal damage was the loss of wood pole lines, copper wire, transformers, and miscellaneous electric-line material. The service in San Diego and immediate vicinity was not seriously interrupted. The lines to the more important towns were reestablished within two weeks, but some of the remote farming districts were without electric service for six weeks or more. The total damage to the gas and electric departments, corrected for value of salvaged material, was $70,527.

*Western Salt Co.*—The losses consisted of 170 acres of salt ground (which was covered with a deep deposit of silt), 2,500 tons of salt, a large quantity of brine in the ponds, and injury to machinery. The total damage was given as $85,500.

*Fenton-Sumption-Barnes Co.*—This company operates a gravel-washing plant in Otay Valley, about a mile from San Diego Bay. This plant was a complete loss, for after the flood there was not an indication on the surface to show its location. The value of this equipment was $35,000. In addition, the soil was entirely removed from 100 acres of bottom land which had been purchased for about $450 per acre. The business loss was complete from January 27 to May 1.

*Indian reservations.*—There was considerable damage to irrigation systems, buildings, and other improvements. In San Diego County the loss was approximately $38,000 and in Riverside County about $9,000.

*Los Angeles Harbor.*—About 2,030,000 yards of silt was deposited in the channels during the flood. These deposits did not reach the outer harbor or even the main turning basin and main entrance channel to an extent sufficient to interfere with commerce or require immediate dredging. At the extreme head of the harbor a channel reopened by a private corporation was filled with silt. There was also considerable silting in the East Basin channel.

*Long Beach Harbor.*—Navigation was greatly inconvenienced by very heavy silting in the different channels and basins. The total deposit of silt was about 1,000,000 yards. The indirect damage to the various industries in the harbor district was probably much greater than the expenditures which will be necessary for dredging.

*United States Geological Survey.*—At the time of the flood the Survey was maintaining 23 river-measurement stations in the region covered by this report. All these stations were seriously damaged. The following equipment was lost: Six water-stage recorders, including wells and shelters; 17 staff gages; 10 cars and cables; and 8 concrete controls. In reequipping the stations it was found necessary, on account of great changes in the stream channels, to relocate two stations and abandon six. The total damage to equipment was about $2,600.

## COMPARISON OF FLOOD OF 1916 WITH PREVIOUS FLOODS IN SOUTHERN CALIFORNIA.

### BASIS OF COMPARISON.

To determine whether the flood of 1916 was more or less severe than previous floods in southern California, a search was made of the early records, and many old residents of the country were interviewed. The results of this work are summarized in the following pages. Of particular interest is the record of wet and dry years, compiled by Mr. A. Campbell, who has lived in San Diego County since 1869. Information as to conditions in most of the years prior to 1840 was taken from records of the Mission Fathers.

| | |
|---|---|
| 1770 | Drought. |
| 1786 | Copious rainfall. |
| 1787 | Rainfall insufficient; crops short. |
| 1791 | Extremely dry; no rain for whole year. |
| 1794 | Rainfall insufficient; crops short. |
| 1795 | Very dry. |
| 1811 | Flood year. |
| 1815 | Flood year. |
| 1819 | Short in rain and crops. |
| 1825 | Great flood changed course of Santa Ana River. |
| 1826<br>1827<br>1828 | Dry years (Gen. Vallejos.) |
| 1832 | Short in rain and crops. |
| 1840–41 | Dryest year ever known. |
| 1841–42 | Wettest year ever known. |
| 1842–43 | Very open and dry. |
| 1843–44 | Very dry; no grain grown in Sacramento Valley |
| 1845 | Drought. |
| 1845–46 | Wet in north; dry in southern California; cattle starved. |
| 1846–47 | Considerable rain; crops good. |
| 1848–49 | Most snowy winter known; rainfall moderate. |
| 1849–50 | One of the wettest and most floody winters. |
| 1850–51 | Open; rainfall moderate. |
| 1853 | Big floods and snow. |
| 1850–1856 | Flood and good years. |
| 1856–57 | Dryest in 20 years. |
| 1857–1862 | Medium rainfalls. |
| 1862–63 | Dry years. |
| 1863–1869 | All good wet years. |
| 1869 | A very exceptional year. In October the thermometer registered 110°, and a rainfall in December is estimated at 12 inches in 24 hours. |
| 1869–70 | Dry season. |
| 1870–71 | Dry season. |
| 1872–74 | Fairly wet seasons. |
| 1875–76 | Good rainfall. |

1876–77....Dry season.
1877–1882..Good seasons.
1882–83....Dry years.
1883–84....Wettest winter known.
1885–1893..Series of good years.
1893–94....Short rainfall.
1895–6–7...Three good wet years.
1897–1900..Three dry years.
1901–1910..Fairly good wet years.
1910–1913..Dry years at end of season.
1912–13....Dry year.

The following additional information was obtained from "A history of California floods and droughts," by J. M. Guinn:

1822. A flood covered the lowlands and rose to a greater height than ever before known.

1851–52. A severe flood year in southern California. At Old Fort Miller on headwaters of San Joaquin River, Dr. W. T. Edgar, surgeon of the post, observed a rainfall of 46 inches during January and February, 1852.

1862. Santa Ana River at Anaheim ran 4 feet deep and spread in an unbroken sheet to Coyote Hills, 3 miles beyond. It rained 30 days in succession, beginning December 24, 1861.

### FLOODS ON TIA JUANA RIVER.

Information concerning early floods on Tia Juana River was also furnished by Mr. Campbell, who considers the flood of 1884 the greatest in total run-off that has occurred during this time. The peak of that flood, however, was not so great as the peaks of the floods of 1891 and 1916, the only years in which, since 1869, water from Tia Juana River overflowed into the Otay drainage basin. In February, 1891, snow was above the fences at Mr. Campbell's ranch in Laguna Mountain divide, and one drift was 21 feet deep. This snow melted during a five days' rain. The lower Tia Juana Valley was flooded about as much in 1891, when the large hotel at Hot Springs, Mexico, was washed away, as in 1916. In comparing these floods the effect of storage at Morena reservoir in 1916 should be considered.

### SWEETWATER RIVER.

Mr. C. H. Ellis, sr., who has lived near Descanso for 35 years, states that the floods of 1884 and 1916 were the largest on Sweetwater River within that period. At the site of the Geological Survey gaging station the water rose 3 to 4 feet higher in 1916 than in 1884. In 1916 the channel was wider and at least 2 feet deeper than in 1884. It is his opinion that the flood of 1916 was approximately double that of 1884.

The information presented in the following table was taken from a copy of the diary of the late William S. Gregg, Dehesa, Cal.:

*Record of flood of 1884.*

| Date. | Rain-fall. | Remarks. | Date. | Rain-fall. | Remarks. |
|---|---|---|---|---|---|
| 1884. | *Inches.* |  | 1884. | *Inches.* |  |
| Feb. 2-3 | 2 | River came with flood Feb. 3. (Total rainfall, October to date, 10 inches.) | Mar. 27 | [illegible] |  |
| 5 | 1½ |  | 28 | 1[illegible] |  |
| 6 | 2 |  | 29 | [illegible] |  |
| 7 | ½ |  | 30-31 | [illegible] | River rose a little. |
| 10-11 | 1 | River rising. | Apr. 10 | 1[illegible] |  |
| 15 | 1½ | Cows over the river, can't get back. | 12-13 | [illegible] |  |
| 16 | 1½ | River higher than for 20 years. | 16 | (a) |  |
| 17-18 | 2½ | River higher. Over road to San Diego in two places. | 28 | ¾ |  |
| 25 | ........ | Cattle, horses, etc., turned over river. | 29 | 1 |  |
| Mar. 3-6 | 2 |  | May 1 | [illegible] |  |
| 7 | ½ |  | 15 | 1½ |  |
| 10 | 1 |  | 18 | ........ | Cloudburst up by Harbinson's. |
| 14-15 | ........ |  | 19 | 1 | Last night. |
| 15 | [illegible] |  | 20 | 1½ | River high. |
| 23 | ¼ |  | June 1 | ........ | Total rainfall for season, 34¾ inches. |
| 26 | ½ |  | 1895. |  |  |
|  |  |  | Jan. 16 | ........ | Sweetwater River very high, higher than for 32 years. Great flood on. Farm covered with water from hill to hill Jan. 17. |

a Showers.

It is of interest to note that Mr. Gregg considered the flood of 1895 greater than that of 1884. The record[1] at Sweetwater reservoir shows that the total run-off of Sweetwater River for the year ending June 30, 1895, was 73,412 acre-feet; the record of J. F. Covert, chief engineer, Sweetwater Water Co., shows that the run-off at Sweetwater reservoir for January 16 to 31, 1916, was 111,000 acre-feet. (See pp. 48–49.) Mr. Covert gives the total run-off from October, 1915, to September, 1916, as 160,580 acre-feet.

### SAN DIEGO RIVER.

The highest known discharge into Cuyamaca reservoir, stated in terms of maximum rate of inflow for 24 hours, is as follows:

|  | Second-feet. |
|---|---|
| 1895, January 17 | 1,630 |
| 1906, March | 1,120 |
| 1916, January 27 | 2,400 |

The following information was obtained in an interview with Mrs. Martha Swycaffer, who came to San Diego in 1854.

Mrs. Swycaffer states that the flood of 1862 was greater than any other within her time. The rain began in the fall of 1861 and the rainy season lasted until June, 1862. Beginning Christmas Day, a rain set in which lasted for at least six weeks, during which time there was not sunshine enough to dry a handkerchief. At about the end of this storm the rain set in more heavily, causing the big flood.

Before the peak the river occupied two channels, one on each side of the Swycaffers' home but a considerable distance from it. The

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[1] McGlashan, H. D., and Dean, H. J., Water resources of California, part 3: U. S. Geol. Survey Water-Supply Paper 300, p. 493, 1913.

Swycaffer house was a two-story brick-veneered building. As the flood increased it was necessary to move into the upper story of the building, all the lower doors and windows being left open to ease the force of the flood. The Swycaffer house was the only one in the San Diego River bottom that stood, and all inhabitants in the vicinity sought refuge in the second story. The refugees were rescued from the second-story window in a surf boat manned by sailors, and Mrs. Swycaffer and three babies were then sheltered in an adobe house in Old Town. During the night a dike built for the protection of Old Town was overtopped, and her refuge was again flooded. The family was carried to the Old Palms and placed under the one which was out of water; the ground at the other was flooded.

The flood of 1862 was of long duration for a southern California stream, as it maintained approximately its peak height for 24 hours. Mrs. Swycaffer does not consider the flood of 1884 as large as that of 1916. In her opinion the flood of 1916 was next in magnitude to that of 1862.

Mrs. Swycaffer was familiar with what is now the Foster and Lakeside country. At Lakeside the high water reached to the old adobe ranch house, or an elevation of the present Lakeside store. At Foster the flood height reached nearly to the top of an immense oak, which was removed when the railway was built. This flood would have washed out all the present buildings in Foster. Previous to 1862 the present site of San Diego (New Town) was on rounded hills; the draws and gullies now existing were begun in 1862. When Mrs. Swycaffer first visited the Warner Hot Springs the springs broke out on a gradually sloping plain; the flood of 1862 made the topography as it is to-day.

Mrs. Swycaffer knew everyone in Old Town in 1862, and no flood within the memory of any or in the traditions of the place was comparable with it.

## SAN LUIS REY RIVER.

In the early days houses and ranch buildings were built on high ground, and the bottom lands along the river channels were used only as pastures. As the number of settlers increased the agricultural lands became more valuble, and at the time of the floods of 1916 the bottom lands had reached a high state of cultivation and buildings were erected where they would be most convenient without any particular thought of the damage from excessive floods.

Mr. P. F. Hubbard, who has lived near San Luis Rey River since 1873, considers that the only flood in his time that is comparable with that of 1916 occurred in 1884. The flood of 1916 was 2 feet higher at his well and the channel was wider than in 1884. The bottom lands in 1884 were covered with brush and trees and the channel did not cut much. As there were no cultivated fields or buildings in the path of the flood the damage was slight.

Mr. Edward Canterini, who has lived in San Luis Rey Valley since 1884, states that there was more rain in 1884 than in 1916 and the flood was of longer duration, but he does not consider that the maximum discharge was as great as in 1916. The river did not have a well-defined channel prior to 1891.

Immediately after the flood of January 27, 1916, Father Doyle, of the Pala Mission, San Diego County, talked with an old Indian who had lived along San Luis Rey River for many years. The Indian stated that this flood was greater than that of 1862. The old mission ditch at Pala, constructed more than 100 years ago, was washed out in a number of places by the flood of 1916, but previous floods had not injured it. Father Doyle considers the flood of 1916 the greatest which has occurred since the valley has been settled. The flood of 1862 he places second in size, and that of 1884, third.

Edward R. Bowen, in a paper on the San Luis Rey floods of January, 1916,[1] says:

> The entire San Luis Rey Valley was inundated, the stream extending from hill to hill—a distance of probably 1½ miles—and covering an area of over 1,000 acres. The drift along the county road on the south side of the valley indicated a 6-foot depth of water at that point. * * * It is probable that the enormous quantities of silt and débris carried by the stream in the first flood, together with that carried by the subsequent one, so built up and raised the old channel of the river that it was at a greater elevation than the adjacent valley lands. When the second flood came down this channel, its banks were overtopped and a new channel formed, cutting across the valley in a northeast to southwest direction, taking a long sweep to the westward at about the middle of the valley and returning to an old course near the narrows. * * * All farms in the valleys of the lower river were completely destroyed and three people were drowned. The entire valley is covered with deposit of sand and silt to an average depth of at least 3 feet, and in many places as much as 6 feet. Conditions along the upper river are not so bad. The valleys are more constricted and the stream better confined, although all crops along the bottom lands have been ruined. [See Pl. IV, *B*, p. 28.]

### TEMECULA CREEK.

Mr. F. L. Fernold, of Temecula, Riverside County, reports that the flood of 1891 in Temecula Canyon rose to a height of about 2 feet on the trunk of a large oak tree on the bank at the ford. A neighbor, who was with him, said that this height was very close to the peak of the flood of 1884. This tree was washed out during the flood of January, 1916, after the water had risen about 12 feet on the trunk. The canyon at this point is in solid rock and conditions would be the same for all floods.

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[1] Eng. News, vol. 75, No. 8, p. 385, Feb. 24, 1916.

### LOS ANGELES AND SAN GABRIEL RIVERS.[1]

There were heavy floods on Los Angeles and San Gabriel rivers in 1825, 1833, 1862, 1867, 1884 (2), 1886, 1889 (2), 1890, 1911, and 1914, and it is said that serious floods occurred also in 1842, 1852, and 1874. From the testimony in the case of Andres Daneri *v.* Southern California Railroad Co., superior court of Los Angeles County, in 1897, the largest floods occurred in 1825 and 1833 and the next largest flood was in 1862. It seems to be generally agreed that the greatest flood since 1862 occurred in 1889. The flood table prepared by the United States Weather Bureau, for the period 1878 to 1914, shows that 41 floods occurred in the vicinity of Los Angeles during this period.

The flood of 1909 in Los Angeles River was observed by H. Hawgood and William Mulholland (then superintendent of the Los Angeles City Water Co.). From the measured cross-section of the channel at the Southen Pacific Co's. crossing, on its main line east, and from the slope of the water surface, together with personal observations of the river at time of flood, Mr. Hawgood estimated that the maximum discharge was in excess of 35,000 second-feet. The details of the computation are not now available. The section observed by Mr. Mulholland was about 1,200 feet north of Buena Vista bridge. Here the surface velocity, as observed from débris floating down the stream, was 14 to 16 miles per hour. The depth of water was given as 9 feet and the width as 300 feet. The discharge, as computed from these data by Mr. Hawgood, was approximately 45,000 second-feet.

## FLOOD RUN-OFF IN JANUARY, 1916.

### COLLECTION OF RECORDS.

At the beginning of the first storm on January 17, Mr. Ebert reached San Gabriel River near Azusa, and on January 17 and 18 he made float measurements just below the gage; the cable was not accessible, as the highway was washed out above the mouth of the canyon. January 20 he attempted to reach Santa Ana River near Mentone, but found the highway impassable east of Highland. The highway west of Azusa was also closed on account of the damage to the San Gabriel bridge. The Pacific Electric Railway was opened from Azusa to Los Angeles January 21.

Mr. Ebert left Los Angeles for San Diego by the inland route January 24 and reached Escondido the night of January 26. The heavy rainfall during that night destroyed the highways in all directions, and he was detained there by the condition of the roads until February 5, when his automobile was drawn across San Dieguito River at Bernardo by a four-horse team, and he reached Lakeside that night by way of Poway grade, Miramar ranch, and Pacific Beach. A measurement could not be made on San Diego River at Lakeside, as the cable had been washed out and the river was flowing in a wide channel to the right of the highway bridge. The following day he visited Sweetwater River near Descanso, but on account of the damage to highways he was unable to reach any other stations in this territory or those on Santa Ysabel Creek and upper San Luis Rey River. He made the return trip from San Diego by boat February 9.

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[1] Abstracted from reports of the Board of Engineers Flood Control to the Board of Supervisors, Los Angeles County, Cal., submitted July 27, 1915, pp. 144-146 and 172-174.

In March, 1916, Mr. McGlashan and Mr. Ebert made an extensive trip through the region covered by this report to obtain available flood data and to collect records obtained by private parties. They visited the river-measurement stations that were accessible at this time, and also a number of streams on which no stations were being maintained. The flood marks were still very distinct, so that it was possible to make numerous measurements of slope and of cross sections of river channels at maximum stage, and to obtain other data necessary for the computation of flood flow. The results were computed by Kutter's formula, after carefully selecting values of *n*. The base data, as well as the computed records, are here published, to enable any engineer engaged in a detailed study of the run-off to make independent computations of the flow.

## TIA JUANA RIVER BASIN.

### GENERAL FEATURES.

Tia Juana River discharges into the Pacific Ocean below San Diego Bay near the Mexican boundary. Its principal tributary, Cottonwood Creek, rises in the Laguna Mountains of the Coast Range and flows southwestward about 32 miles to its junction with Tia Juana River at the Mexican boundary, about 22 miles east of the coast line. The total drainage area of Cottonwood Creek above its junction with Tia Juana River is approximately 340 square miles. It lies south of the Sweetwater and Otay River basins, and is the most southerly stream in San Diego County. Pine Valley Creek, which joins it 20 miles below its source, is its only important tributary.

The topography of the basin of Cottonwood Creek is rough throughout, although some valley areas are found above the 3,000-foot contour. Below this elevation the stream flows through a deep, narrow canyon, broken only by a short stretch of open country with comparatively light grade at the junction of Pine Valley Creek. Altitudes range from 600 feet above sea level, where the creek joins Tia Juana River, to 5,000 feet on the Laguna Mountains.

The Cottonwood basin is poorly forested. The timber consists of scattered oaks, cottonwoods, and alders, which are restricted almost entirely to the small valleys along the stream and to the higher elevations. The mountain slopes are fairly well covered with brush.

The mean annual rainfall ranges fron 8 to 10 inches along the foothills and from 20 to 30 inches in the mountains.

### COTTONWOOD CREEK AT MORENA RESERVOIR, CAL.[1]

**Location.**—In the SW. ¼ sec. 14, T. 17 S., R. 4 E., three-fourths mile north of Morena Butte, 1¾ miles above mouth of Hauser Creek, and 8½ miles upstream from Barrett dam, San Diego County.

**Drainage area.**—119.5 square miles (reported by George Cromwell).

**Elevation.**—About 3,000 feet above sea level.

**Discharge.**—Computed from gage-height record showing storage in reservoir, corrected for waste through spillways and outlet tower.

**Spillway.**—Consists of 12 openings, each 8½ feet in length, controlled by independent radial gates. All gates were open until 7 a. m., January 29, when 11 were closed. At 11 a. m., January 29, 6 gates were opened and at 5 p. m. the remainder were opened. January 30 at 7 a. m., all gates were closed. Two gates were opened at 7 a. m., January 31 and the remainder at 6 p. m.

Average depth of water in spillway was as follows: January 28, 4 feet; January 29, 3.25 feet; January 31, 3 feet. Considerable drift collected at the spillway which interfered with the operation of the gates.

Maximum capacity of spillway, 5,380 second-feet and of outlet tower, 483 second-feet.

**Outlet tower.**—There are 5 valves in the tower. Number 4, at 99.5 feet, was opened January 28 at 1.30 a. m. and closed January 29 at 6.30 a. m. No other valves were opened during the month.

**Maximum discharge in January, 1916.**—January 27, 7 a. m. to 4 p. m., 8,785 second-feet; 4 p. m. to 6 p. m., 15,356 second-feet; 6 p. m. to 12 p. m., 13,344 second-feet. January 28, 12 a. m. to 7 a. m., 3,157 second-feet.

The following table contains data furnished by George Cromwell, city engineer, San Diego, Cal.:

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[1] O'Shaughnessy, M. M., Construction of the Morena rock-fill dam, San Diego County, Cal.: Am. Soc. Civil Eng. Trans., vol. 75, p. 27, 1913.

*Gage height and discharge of Cottonwood Creek at Morena reservoir, Cal., for January, 1916.*

| Day (7 a. m.) | Gage height (feet). | Storage (million gallons). | Waste. | | Run-off from drainage basin. | | |
|---|---|---|---|---|---|---|---|
| | | | Million gallons. | Acre-feet. | Million gallons. | Acre-feet. | Second-feet. |
| Jan. 1 | 118.68 | 5,189 | | | 4 | 12.3 | 6.2 |
| 2 | 118.70 | 5,193 | | | 2 | 6.1 | 3.1 |
| 3 | 118.71 | 5,195 | | | 4 | 12.3 | 6.2 |
| 4 | 118.73 | 5,199 | | | 9 | 27.6 | 13.9 |
| 5 | 118.77 | 5,208 | | | 4 | 12.3 | 6.2 |
| 6 | 118.79 | 5,212 | | | 5 | 15.4 | 7.7 |
| 7 | 118.82 | 5,217 | | | 4 | 12.3 | 6.2 |
| 8 | 118.84 | 5,221 | | | 10 | 30.7 | 15.5 |
| 9 | 118.89 | 5,231 | | | 6 | 18.4 | 9.3 |
| 10 | 118.92 | 5,237 | | | 38 | 116.7 | 58.8 |
| 11 | 119.11 | 5,275 | | | 12 | 36.0 | 18.6 |
| 12 | 119.17 | 5,287 | | | 4 | 12.3 | 6.2 |
| 13 | 119.19 | 5,291 | | | 4 | 12.3 | 6.2 |
| 14 | 119.21 | 5,295 | | | 103 | 416.8 | 159.4 |
| 15 | 119.72 | 5,398 | | | 77 | 236.4 | 119.2 |
| 16 | 120.01 | 5,475 | | | 910 | 2,793.7 | 1,408.6 |
| 17 | 124.19 | 6,385 | | | 1,469 | 4,509.8 | 2,273.0 |
| 18 | 130.00 | 7,854 | | | 1,248 | 8,831.4 | 1,931.0 |
| 19 | 134.20 | 9,102 | | | 318 | 976.3 | 492.3 |
| 20 | 135.21 | 9,420 | | | 214 | 656.9 | 331.7 |
| 21 | 135.80 | 9,634 | | | 120 | 368.4 | 185.7 |
| 22 | 136.17 | 9,754 | | | 109 | 334.6 | 168.7 |
| 23 | 136.51 | 9,863 | | | 93 | 285.5 | 143.9 |
| 24 | 136.80 | 9,956 | | | 115 | 353.1 | 178.2 |
| 25 | 137.15 | 10,071 | | | 169 | 518.8 | 261.6 |
| 26 | 137.64 | 10,240 | | | 271 | 831.9 | 419.5 |
| 27 | 138.40 | 10,511 | 768 | 2,357.6 | 5,707 | 17,520.5 | 8,834.3 |
| 28 | 150.50 | 15,450 | 1,728 | 5,304.9 | 1,278 | 3,923.5 | 1,978.3 |
| 29 | 149.50 | 15,000 | 900 | 2,763.0 | 675 | 2,072.3 | 1,044.8 |
| 30 | 149.00 | 14,775 | | | 225 | 690.7 | 348.2 |
| 31 | 149.50 | 15,000 | 659 | | 211 | 647.7 | 326.6 |
| Feb. 1 | 148.50 | 14,552 | | | | | |

| Total run-off for month | |
|---|---|
| acre-feet | 41,200 |
| depth in inches on drainage area | 6.43 |

## OTAY RIVER BASIN.

### GENERAL FEATURES.

Otay River drains the region between Sweetwater basin on the north and Tia Juana on the east and south. Above Lower Otay dam it has a drainage area of 98.6 square miles. The general course of the stream is southwest, and it enters San Diego Bay at the extreme southern end, about 4 miles north of the International boundary.

Above Lower Otay reservoir the stream is known as Jamul Creek, to which Dulzura Creek is tributary. The natural run-off from this area is increased by the water diverted from Cottonwood Creek through Dulzura conduit, into Dulzura Creek. The drainage area of Jamul Creek is mountainous and the slopes are very steep. The highest point is Lyons Peak; elevation, 3,755 feet. The forest cover is mainly brush, except in the vicinity of the stream channels.

The mean annual precipitation ranges approximately from 8 to 20 inches.

### OTAY RIVER AT LOWER OTAY RESERVOIR,[1] NEAR OTAY, CAL.

LOCATION.—The dam was in the extreme northwest corner of sec. 18, T. 18 S., R. 1 E., at the head of the canyon above Otay Valley, about 16 miles southeast of San Diego and 8 miles east of Otay, San Diego County.

DRAINAGE AREA.—98.6 square miles (measured on topographic map; includes 12.7 square miles, tributary to Upper Otay reservoir)

ELEVATION.—Top of dam was about 480 feet above sea level.

GAGE.—Vertical staff fastened to outlet tower (Pl. II, *A*). Zero of gage, 346.65 feet above sea level, U. S. Geological Survey datum. The gage-height record for January 22–27, 1916, given in the storage table for the reservoir, was obtained from employees at the reservoir a short time after the dam failed. The record January 15–21 was published in the Engineering Record for February 12, 1916.

SPILLWAY.—Built of concrete at left of dam; width on bottom, 37.9 feet; width at top, 41.5 feet; depth, 8 feet; uniform slope, 0.00365. Floor of spillway is 123.3 feet above zero of gage. It is stated that the spillway has the same dimensions throughout its length, and hence did not admit sufficient water to fill the channel for its entire length. The discharge of the spillway at the time the dam failed was 4,700 second-feet according to George Cromwell, city engineer.[2] John L. Bacon, former assistant city manager, estimated the maximum discharge of the spillway as 2,000,000,000 gallons daily, or 3,100 second-feet.[3]

OUTLET TUNNEL.—There was no provision for blow-off from the reservoir except through the outlet tunnel, which connected with the pipe line to San Diego. At the lower end of the tunnel there was a Y connection with a 36-inch blow-off valve, which was opened at noon January 27, 1916. The maximum capacity through this blow-off was 330 second-feet, according to George Cromwell, city engineer.[4]

MAXIMUM DISCHARGE IN JANUARY, 1916.—The maximum gage height in the reservoir was reported as 134.0 feet at 5.05 p. m., January 27, at which time the dam failed. From the table showing storage in reservoir, the rate of inflow from 4.25 p. m. to 5.05 p. m. was 32,700 second-feet. If the maximum discharge of the spillway as given by the city engineer is added, the total was 37,400 second-feet, or 379 second-feet per square mile of drainage area.

Data concerning cross sections and slope were obtained on Jamul Creek (see p. 45) just above effect of backwater from the reservoir. The maximum discharge at this point was computed as 18,100 second-feet, or 259 second-feet per square mile of drainage area. If this same rate of run-off is assumed for the 12.7 square miles of drainage area above Upper Otay dam, the maximum flow over the dam and through spillway did not exceed 3,300 second-feet.

George Cromwell, city engineer,[4] stated that the run-off into the Lower Otay reservoir was 23,500 second-feet for a period of one hour prior to the failure of the dam. This rate would allow a run-off from the drainage area directly tributary to the reservoir, exclusive of Upper Otay reservoir and Jamul Creek, of 2,100 second-feet, or 130 second-feet per square mile, provided the crest discharges all reached Lower Otay reservoir at the same time.

The maximum discharge computed from the reservoir record exceeds that published by Mr. Campbell by nearly 60 per cent. The run-off per square mile computed from the reservoir record is more than 50 per cent greater than that reported for Sweetwater River at Sweetwater dam. See table of crest discharge (p. 23) for maximum discharge for other streams in this region. The mean rainfall, computed for drainage area above Lower Otay dam, was 19.2 inches; that for Sweetwater River above Sweetwater dam was 21.8 inches. (See table, p. 11.)

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[1] See pp. 25–26 for description of failure of dam on Jan. 27, 1916.

[2] Eng. News, Apr. 13, 1916, p. 717.

[3] Idem, Feb. 3, 1916, pp. 236–239.

[4] Idem, Apr. 13, 1916, p. 718.

**Authority.**—Data for this station were obtained in the field, from the publications cited, and from other reliable sources. Data collected by the city of San Diego were withheld because of pending litigation.

*Storage in Lower Otay reservoir for January, 1916.*

| Date. | Time. | Gage height (feet). | Available storage. | | Increase in storage.[a] | |
|---|---|---|---|---|---|---|
| | | | Million gallons. | Acre-feet. | Acre-feet. | Second-feet. |
| Jan. 15 | | 84.0 | 3,610 | 11,100 | | |
| 17 | | 101.0 | 6,230 | 19,100 | 8,000 | 2,020 |
| 18 | | 111.0 | 8,350 | 25,600 | 6,500 | 3,280 |
| 19 | | 118.7 | 10,200 | 31,300 | 5,700 | 2,870 |
| 21 | | 122.8 | 11,340 | 34,800 | 3,500 | 882 |
| 22 | 7 a. m. | 123.3 | 11,490 | 35,300 | 500 | 252 |
| 23 | 7 a. m. | 123.6 | 11,580 | 35,600 | 300 | 151 |
| 24 | 7 a. m. | 123.8 | 11,640 | 35,700 | 100 | 50 |
| 25 | 7 a. m. | 123.95 | 11,680 | 35,900 | 200 | 101 |
| 26 | 7 a. m. | 124.0 | 11,700 | 35,900 | 0 | 0 |
| 27 | 7 a. m. | 124.9 | 11,970 | 36,700 | 800 | 403 |
| | Noon | 127.9 | 12,950 | 39,800 | 3,100 | 7,500 |
| | 3 p. m. | 130.0 | 13,650 | 41,900 | 2,100 | 8,470 |
| | 4 p. m. | 131.3 | 14,080 | 43,200 | 1,300 | 15,700 |
| | 4.25 p. m. | 132.3 | 14,440 | 44,300 | 1,100 | 31,900 |
| | 5.05 p. m. | 134.0 | 15,030 | 46,100 | 1,800 | 32,700 |

[a] Discharge through spillway not included.

Note.—The available storage in million gallons, given in the above table, was taken from a capacity curve compiled in the office of the city engineer, San Diego. Gage-height record, Jan. 15-21, was published in Engineering Record for Feb. 12, 1916; Jan. 22-27 was obtained from employees of the city of San Diego at the dam a short time after the failure.

### JAMUL CREEK NEAR OTAY, CAL.

**Location.**—In sec. 4, T. 18 S., R. 1 E., about 500 feet above highway crossing above Harvey ranch and well above backwater from Lower Otay reservoir at high-water elevation, and about 11 miles east of Otay, San Diego County.

**Drainage area.**—69.8 square miles (measured on topographic map).

**Elevation.**—About 500 feet above sea level.

**Channel.**—Composed of sand, gravel, and boulders; practically straight for the section covered by slope data, but curves to the left just below point where lower cross section was taken. Banks high and practically clean after flood (Pl. X, *B*). Channel apparently fairly permanent.

**Maximum discharge in January, 1916.**—Measurements of slope and of two cross sections were made March 17, 1916. Slope of water surface that day was determined for a distance of 935 feet. The determination of high-water slope checked fairly well with that of the slope of the water surface March 17, but could not be ascertained so accurately on account of the roughness of the banks. The maximum discharge has been computed as follows: Mean width, 158 feet; mean area, 1,360 square feet; mean wet perimeter, 164 feet; mean hydraulic radius, 8.3; present slope of water surface, 0.0071 (for 935 feet) March 17, 1916. If the value of *n* in Kutter's formula is assumed as 0.04, the discharge is 18,100 second-feet, or 259 second-feet per square mile of drainage area.

## SWEETWATER RIVER BASIN.

### GENERAL FEATURES.

Sweetwater River rises in the south and east slope of the Cuyamaca Mountains of the Coast Range, flows nearly due south for 15 miles, then turns to the west and southwest and discharges into San Diego Bay south of National City. Its length is 45 miles, and its area comprises approximately 215 square miles, the greater part of which is in mountainous country. The basin is extremely narrow. It lies directly south of San Diego River and north of the Otay River and Cottonwood Creek basins.

The topography is not so rough as that of San Diego River basin, although the mountains and foothills extend within 3 or 4 miles of the shore line of San Diego Bay, and the valley and mesa lands are not so extensive as along San Diego River. The basin is poorly forested. The timber is confined almost to the immediate valleys of the streams and to the higher mountain areas. The mountain slopes have a fairly good covering of brush, but the lower foothills are almost bare, supporting only a sparse growth of low brush.

The mean annual rainfall varies from 10 to 15 inches along the foothill belt and from 20 to 45 inches in the mountains.

A considerable area lying between San Diego Bay and the foothills south from National City to the Mexican boundary is under a high state of cultivation. The greater part of this land is irrigated by water taken from Sweetwater River.

### SWEETWATER RIVER NEAR DESCANSO, CAL.

**Location.**—In the SE. ¼ sec. 25, T. 15 S., R. 3 E., at Ellis ranch, 2 miles below mouth of Guatay Creek and about 1½ miles below Descanso, San Diego County.

**Drainage area.**—43.7 miles (measured on topographic and military-survey maps).

**Elevation.**—About 3,300 feet above sea level.

**Records available.**—November 21, 1905, to January, 1916.

**Gage.**—Staff in three sections on left bank at concrete control, a short distance below intake of Ellis ditch; destroyed by the flood of January, 1916. Installed at same datum and practically same location as previous gage.

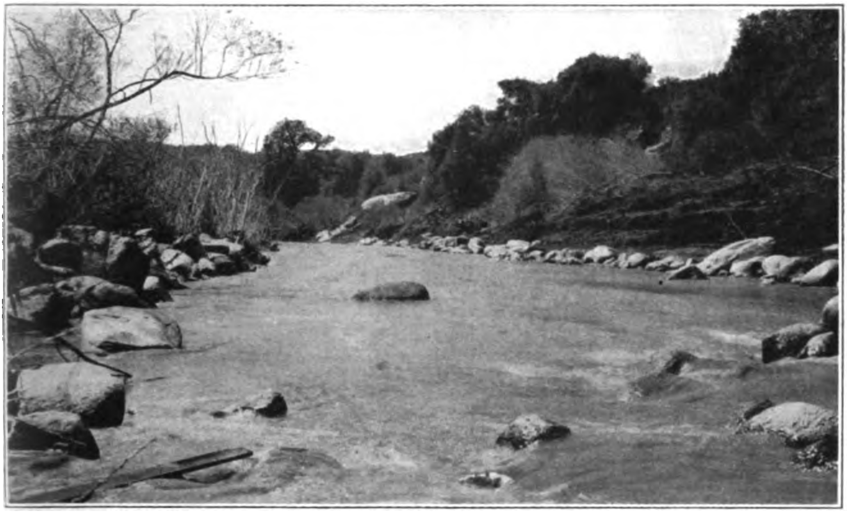
**Discharge measurements.**—Made from cable at gage or by wading. No measurements were made during the flood of January, 1916, as the highways were impassable.

**Channel and control.**—Channel composed of sand, fine gravel, and boulders; shifting. Banks are high and not subject to overflow. A concrete control constructed October 11, 1914, across the channel opposite original gage was practically destroyed by the flood of January, 1916.

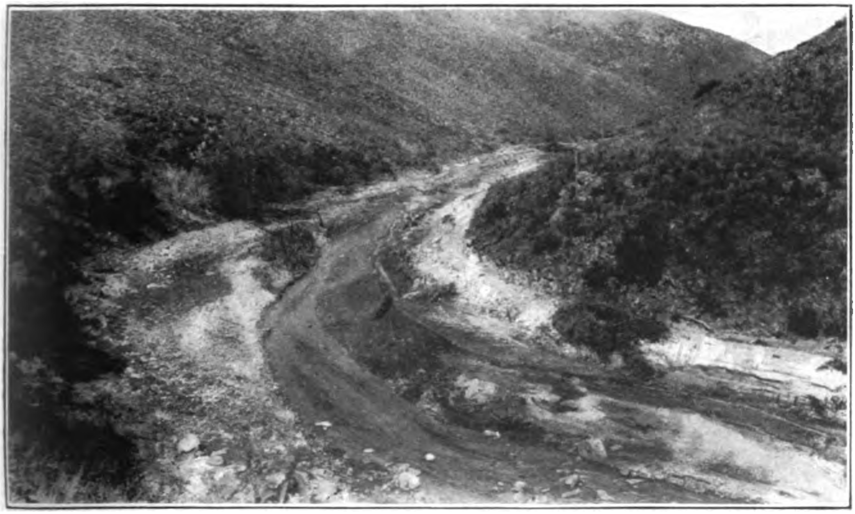
**Extremes of discharge.**—1905–1915: Maximum stage recorded, 9.25 feet at 5 p. m. March 24, 1906 (approximate discharge, computed from extension of rating curve, 3,000 second-feet); channel dry during a portion of the years 1910, 1911, and 1913.

**Maximum discharge in January, 1916.**—No gage-height record after January 23, when gage was washed out. Measurements of slope and two cross sections were made March 13, 1916, in the vicinity of the gaging station. The channel (Pl. X, *A*), is practically straight for the section covered by slope data. Banks high and covered with brush and small trees.

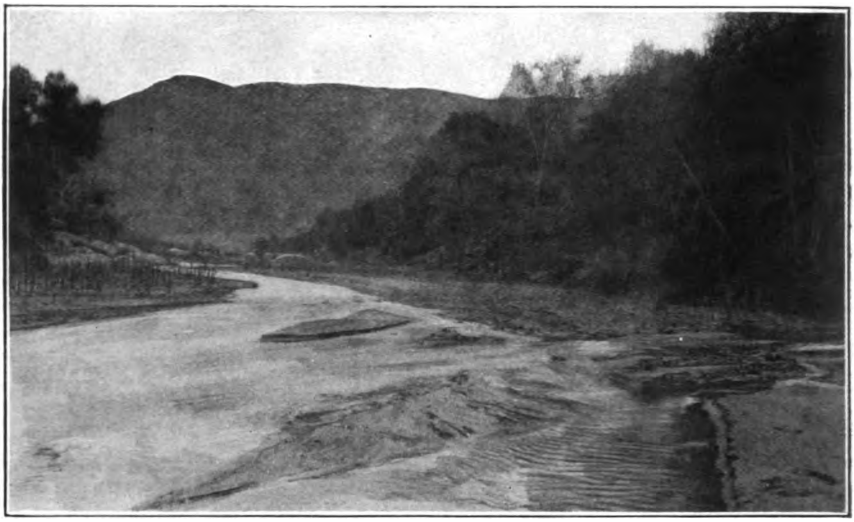
The maximum discharge has been computed from the mean of the two cross-sections, as follows: Mean area, 987 square feet; mean hydraulic radius, 6.0; slope of water surface, 0.0078 (for 875 feet) March 13. If the value of $n$ in Kutter's formula is assumed as 0.045, the discharge is 9,870 second-feet, or 226 second-feet per square mile of drainage area.



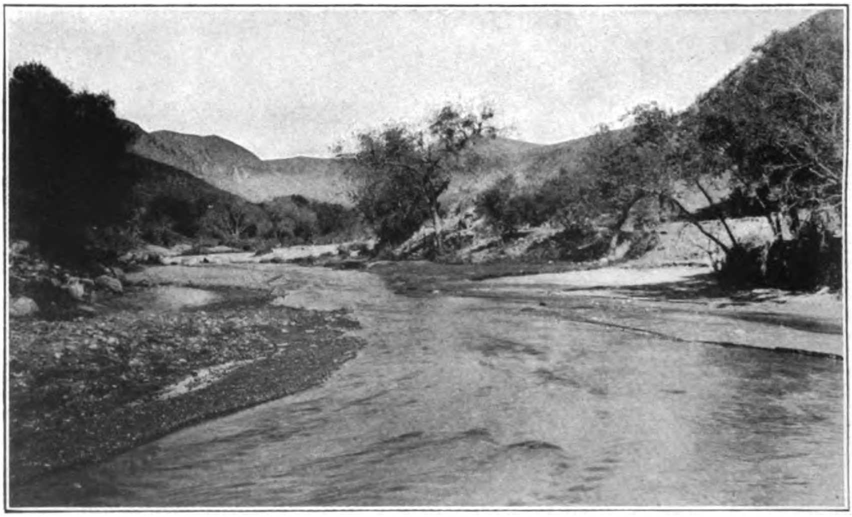
*A.* VIEW DOWNSTREAM ON SWEETWATER RIVER NEAR DESCANSO, AFTER FLOOD OF JANUARY, 1916.



*B.* VIEW UPSTREAM ON JAMUL CREEK NEAR OTAY, AFTER FLOOD OF JANUARY, 1916.



*A.* VIEW UPSTREAM SHOWING CAPITAN GRANDE DAM SITE ON SAN DIEGO RIVER, AFTER FLOOD OF JANUARY, 1916.



*B.* VIEW UPSTREAM ON SAN VICENTE CREEK AT FOSTER, AFTER FLOOD OF JANUARY, 1916.

**Accuracy.**—Determinations of discharge January 16 to 22, roughly approximate as they are computed from an extension of the rating curve for 1914-15, which is unsupported by high-water measurements. It is assumed that the concrete control was not disturbed until the second rise, which occurred January 27.

*Gage height, in feet, and discharge, in second-feet, of Sweetwater River near Descanso, Cal., for January, 1916.*

| Date. | 9 a. m. | | 5 p. m. | |
|---|---|---|---|---|
| | Gage height. | Discharge. | Gage height. | Discharge. |
| Jan. 14 | 1.38 | 21 | 1.38 | 21 |
| 15 | 2.20 | 137 | 2.20 | 137 |
| 16 | 2.30 | 159 | 4.40 | 1,060 |
| 17 | 6.00 | 2,500 | 6.00 | 2,500 |
| 18 | 6.00 | 2,500 | 4.70 | 1,290 |
| 19 | 4.00 | 822 | 3.80 | 716 |
| 20 | 3.70 | 666 | 3.50 | 570 |
| 21 | 3.50 | 570 | 3.50 | 570 |
| 22 | 3.50 | 570 | 3.80 | 716 |

Note.—For maximum discharge during January see description of station. No record Jan. 23 to 31, as gage was washed out.

### SWEETWATER RIVER NEAR DEHESA, CAL.

**Location.**—In the NW. ¼ NW. ¼ sec. 20, T. 16 S., R. 2 E., at Sloane ranch, 1,000 feet below mouth of Lawson Creek, about 3 miles southeast of Dehesa, San Diego County.

**Drainage area.**—112 square miles (measured on topographic and military-survey maps).

**Elevation.**—About 900 feet above sea level.

**Records available.**—December 4, 1913, to January, 1916.

**Gage.**—Bristol water-stage recorder on left bank 5 feet above control; destroyed by flood of January, 1916. No gage-height record available for that month.

**Discharge measurements.**—Made from cable 200 feet below concrete control or by wading; equipment destroyed by flood, January, 1916; no discharge measurements were made during that month.

**Channel and control.**—Bed composed of shifting sand overlying solid rock. The concrete control, which extended to bed rock, was destroyed by the flood of January, 1916. Banks are high and not subject to overflow.

**Extremes of discharge.**—1913-1915: Maximum stage recorded, 5.8 feet February 11, 1915 (approximate discharge computed from extension of rating curve, 1,750 second-feet); channel practically dry August 12, 1915, to end of year.

**Maximum discharge in January, 1916.**—Mr. J. F. Covert, chief engineer, Sweetwater Water Co., measured cross sections and obtained slope data at this station.

Determinations of maximum discharge for the flood of January, 1916, based on these data, were furnished by F. C. Finkle, consulting engineer, as follows: Mean area, 1,639 square feet; mean wet perimeter, 184 feet; mean hydraulic radius, 8.9; slope, .0047; assumed value of *n* in Kutter's formula, .03; coefficient c., 72.5; mean velocity, 14.82 feet per second; discharge, 24,295 second-feet or 217 second-feet per square mile of drainage area.

### SWEETWATER RIVER AT RUDOLPH RANCH, NEAR DEHESA, CAL.

From measurements of cross sections and slope at the highway crossing near south line of sec. 14, T. 16 S., R. 1 E., San Diego County, made by J. F. Covert, chief engineer, Sweetwater Water Co., the maximum discharge for the flood of January, 1916, was computed and furnished by F. C. Finkle, consulting engineer, as follows: Mean area, 2,382 square feet; mean wet perimeter, 485 feet; mean hydraulic radius, 4.9; slope, 0.0045; assumed value of *n* in Kutter's formula, 0.025; coefficient c, 77.9; mean velocity, 11.56 feet per second; discharge, 27,530 second-feet or 204 second-feet per square mile (drainage area given as 135 square miles).

### SWEETWATER RIVER NEAR JAMACHO, CAL.

Measurements of cross sections and slope made by J. F. Covert, chief engineer, Sweetwater Water Co., at Jamacho Canyon, San Diego County, were used by F. C. Finkle, consulting engineer, to compute the maximum discharge for the flood of January, 1916, with the following results:

Mean area, 3,006 square feet; mean wet perimeter, 410 feet; mean hydraulic radius, 7.3; slope, 0.0057; assumed value of *n* in Kutter's formula, 0.03; coefficient c, 70.2; mean velocity, 14.3 feet per second; discharge, 43,002 second-feet or 250 second-feet per square mile (drainage area given as 172 square miles).

### SWEETWATER RIVER AT SWEETWATER DAM, CAL.

The following table was prepared by J. F. Covert, chief engineer, Sweetwater Water Co., for court use. It is known as Exhibit L in the Neuman case and Exhibit J in the Sutliff case. Sweetwater reservoir is on Sweetwater River about 6½ miles northeast of National City, San Diego County. The drainage area tributary to the reservoir is 181 square miles (measured on topographic and military survey maps).

*Discharge, in second-feet, of Sweetwater River at Sweetwater dam, Cal., for Jan. 16 to 31, 1916.*

| Date. | Time. | Accumulative run-off. | Waste. | | | | Total discharge. | Mean daily discharge. |
|---|---|---|---|---|---|---|---|---|
| | | | Through blow-off. | Spillway. | Over parapet. | Through breaks. | | |
| Jan. 16 | 8 a. m. to 5 p. m. | 809 | | | | | 809 | 1,530 |
| 16-17 | 5 p. m. to 3 a. m | 4,215 | | | | | 4,215 | |
| 17 | 3 a. m. to 8 a. m. | 6,050 | | | | | 6,050 | 5,870 |
| 17 | 8 a. m. to 11 a. m. | 4,185 | 232 | | | | 4,417 | |
| 17 | 11 a. m. to 3.15 p. m. | 4,185 | 232 | | | | 4,417 | |
| 17 | 3.15 p. m. to 5.15 p. m. | 5,950 | 232 | | | | 6,182 | |
| 17 | 5.15 p. m. to 9 p. m. | 9,090 | 232 | | | | 9,322 | |
| 17 | 9 p. m to 11 p. m. | 5,580 | 232 | | | | 5,812 | |
| 17-18 | 11 p. m. to 3 a. m. | 6,130 | 232 | 560 | | | 6,922 | |
| 18 | 3 a. m to 5 a. m. | 6,130 | 232 | 1,629 | | | 7,991 | 5,900 |
| 18 | 5 a. m to 8 a. m | 1,740 | 232 | 2,358.2 | | | 4,330 | |
| 18 | 8 a. m. to 12 m | 2,500 | 372 | 2,775.7 | | | 5,648 | |
| 18 | 12 m. to 5 p. m. | 2,500 | 719 | 3,220 | | | 6,439 | |
| 18 | 5 p. m. to 8.30 p. m. | 1,488 | 720 | 3,658 | | | 5,866 | |
| 18 | 8.30 p. m. to 10.30 p. m | 802 | 721 | 3,932 | | | 5,455 | |
| 18-19 | 10.30 p. m to 4.30 a. m. | − 689 | 719 | 3,737.6 | | | 3,768 | |
| 19 | 4.30 a. m. to 5 p. m. | −1,248 | 716 | 3,297.7 | | | 2,766 | 2,770 |
| 19-20 | 5 p. m. to 6 a. m. | −1,186 | 714 | 2,606.7 | | | 2,135 | |
| 20 | 6 a. m to 5 p. m | −1,023 | 711 | 1,586.5 | | | 1,274 | 1,4[illegible] |
| 20-21 | 5 p. m to 7 a. m. | − 495 | 709 | 883 | | | 1,097 | |
| 21 | 7 a. m. to 5 p. m. | − 600 | 706 | 518.5 | | | 625 | 707 |
| 21-22 | 5 p. m. to 5 a. m | − 87 | 181 | 340.5 | | | 434 | |
| 22 | 5 a. m. to 8 a. m. | | 181 | 157.5 | | | 339 | 356 |
| 22 | 8 a. m. to 5 p. m. | 339 | | | | | 339 | |
| 22-23 | 5 p. m. to 8 a. m. | 331 | | | | | 331 | |
| 23 | 8 a. m. to 5 p. m. | 318 | | | | | 318 | 295 |
| 23-24 | 5 p. m. to 7 a. m. | 225 | | | | | 225 | |
| 24 | 7 a. m to 5 p. m | 215.5 | | 23.8 | | | 239 | 228 |
| 24-25 | 5 p. m. to 7 a. m. | 126.5 | | 83.1 | | | 210 | 277 |
| 25-26 | 7 a. m. to 7 a. m | 112.8 | | 190.6 | | | 304 | 367 |
| 26-27 | 7 a. m. to 4.30 a. m. | 77.2 | | 316 | | | 393 | |
| 27 | 4.30 a. m. to 7 a. m. | 1,850 | | 545 | | | 2,395 | 15,000 |
| 27 | 7 a. m. to 9 a. m. | 1,928 | 326 | 895 | | | 3,149 | |
| 27 | 9 a. m. to 11 a. m. | 1,948 | 347 | 1,314 | | | 3,609 | |
| 27 | 11 a. m. to 11.45 a. m. | 7,790 | 368 | 1,803 | | | 9,961 | |
| 27 | 11.45 a. m. to 1 p. m. | 13,060 | 368 | 2,826 | | | 16,254 | |
| 27 | 1 p. m to 2.20 p. m. | 17,180 | 368 | 4,063 | | | 21,611 | |
| 27 | 2.20 p. m. to 4.08 p. m. | 24,200 | 408 | 4,953.4 | 3,860 | | 33,421 | |
| 27 | 4.08 p. m. to 4.30 p. m. | 16,280 | 448.5 | 5,460.4 | 8,530 | 8,181 | 38,900 | |
| 27 | 4.30 p. m. to 5.30 p. m. | −2,550 | 449 | 5,503 | 9,090 | 33,008 | 45,500 | |
| 27 | 5.30 p. m. to 6.30 p. m. | −43,300 | 444 | 5,049 | 4,420 | 70,487 | 37,100 | |
| 27 | 6.30 p. m. to 9 p. m. | −31,050 | 434 | 2,314 | | 59,902 | 31,600 | |
| 27-28 | 9 p. m. to 8 a. m. | −9,870 | 419.8 | | | 25,050 | 15,600 | |
| 28 | 8 a. m. to 5 p. m. | −5,970 | 400 | | | 14,570 | 9,000 | 9,970 |
| 29 | | −1,288 | 429 | | | 5,649 | 4,790 | 4,790 |
| 30 | | − 481 | 469 | | | 4,022 | 4,000 | 4,000 |
| 31 | | − 369.5 | 469 | | | 2,640 | 2,740 | 2,740 |

| Total run-off for period | |
|---|---|
| acre-feet | 111,000 |
| depth in inches on drainage area | 11.55 |

NOTE.—Mean daily discharge, total discharge in acre-feet, and run-off in depth in inches computed by Engineers of United States Geological Survey.

## SAN DIEGO RIVER BASIN.

### GENERAL FEATURES.

San Diego River rises in the Cuyamaca Mountains, on the western slope of the Coast Range, flows southwestward, and discharges into Pacific Ocean through False Bay at the northern boundary of San Diego City. Its length is about 50 miles, half of which lies in the mountains above the town of Lakeside. The San Diego basin has an area of 434 square miles and lies directly south of the San Dieguito basin and north of the Sweetwater River basin.

The San Diego has several small tributaries, the most important being Coleman, Cedar, Boulder, South Fork, and Chocolate creeks, all of which enter from the east and south above Lakeside. San Vicente Creek, the only important tributary from the north, enters the river at Lakeside.

The upper part of the basin above Lakeside is extremely rough and rugged, but below Lakeside numerous valleys and high mesa lands extend to the coast. Elevations throughout the basin range from 50 to 600 feet in the foothills and from 600 to 6,000 feet in the mountains. Cuyamaca Peak, the highest point in the basin, has an elevation of 6,028 feet. The formation is the loose granite that is typical of all river basins in San Diego County.

The San Diego basin is poorly forested. The timber is confined almost entirely to the valley along the streams and to the higher mountain areas. The mountain slopes are fairly well covered with brush, but the lower foothills are almost entirely bare, supporting only a scattered growth of low brush.

The mean annual rainfall ranges from 10 to 15 inches along the foothill belt, and from 20 to 45 inches in the mountains.

Irrigation is carried on extensively in the valleys and on the mesa lands between Lakeside and San Diego, and additional areas might be irrigated if an adequate supply of water could be assured. Two storage reservoirs have been constructed: The Cuyamaca reservoir is on Boulder Creek, at an elevation of 4,600 feet above sea level, and has a capacity of 11,400 acre-feet with a 35-foot earthen dam. La Mesa reservoir is in the foothills about 2 miles northwest of the town of La Mesa, at an elevation of 435 feet. The dam is of earth and rock, is 66 feet high, and has a storage capacity of about 1,500 acre-feet. La Mesa reservoir is filled by water diverted from San Diego River during the winter months.

### SAN DIEGO RIVER AT DIVERTING DAM NEAR LAKESIDE, CAL.

**Location.**—In the NE. ¼ sec. 11, T. 14 S., R. 2 E., at the intake of San Diego flume, 1,000 feet below mouth of Boulder Creek, and about 13 miles northeast of Lakeside, San Diego County.

**Drainage area.**—102 square miles (measured on topographic maps).

**Elevation.**—About 800 feet above sea level.

**Records available.**—October 1, 1912 to January, 1916.

**Extremes of discharge.**—1912–1915: Maximum stage recorded, 11.6 feet January 27, 1914, and March 20, 1915 (discharge, 2,380 second-feet); no flow over dam for several months during each year. The low-water discharge is diverted into San Diego flume.

**Discharge for January, 1916.**—Mr. W. S. Post, consulting engineer for Cuyamaca Water Co., furnished the tables of discharge for the month of January, 1916. A rating curve has been developed by the Geological Survey covering the discharge to 2,400 second-feet. The discharge during the flood periods was computed from a weir formula for the dam.

STORAGE.—See Cuyamaca reservoir near Julian, Cal.

ACCURACY.—The maximum discharge for January, 1916, as determined by the weir formula, was checked by data on slope and cross section obtained after the flood.

*Discharge, in second-feet, of San Diego River at diverting dam near Lakeside, Cal., for January, 1916.*

| Date. | Hour. | Instantaneous discharge. | Instantaneous Cuyamaca Waste. | Instantaneous discharge from 90 square miles.[a] |
|---|---|---|---|---|
| Jan. 13 | 6 a. m. | 24 | 0 | 24 |
| 14 | 6 a. m. | 24 | 0 | 22 |
| | 6 p. m. | 28 | 0 | 28 |
| 15 | 6 a. m. | 130 | 0 | 130 |
| | 6 p. m. | 130 | 0 | 130 |
| 16 | 6 a. m. | 130 | 0 | 130 |
| | 6 p. m. | 349 | 0 | 349 |
| 17 | 6 a. m. | 4,120 | 0 | 4,120 |
| 18 | 6 a. m. | 4,710 | 0 | 4,710 |
| | 12 m. | 1,970 | 0 | 1,970 |
| 19 | 6 a. m. | 1,970 | 110 | 1,860 |
| | 12 m. | 2,190 | 110 | 2,080 |
| | 6 p. m. | 1,560 | 110 | 1,450 |
| | 12 p. m. | 7,030 | 110 | 6,920 |
| 20 | 6 a. m. | 1,070 | 110 | 960 |
| | 12 m. | 1,070 | 110 | 960 |
| | 6 p. m. | 350 | 110 | 240 |
| 21 | 6 a. m. | 526 | 106 | 420 |
| | 6 p. m. | 540 | 0 | 540 |
| 22 | 6 a. m. | 346 | 0 | 346 |
| | 6 p. m. | 271 | 0 | 271 |
| 23 | 6 a. m. | 205 | 0 | 205 |
| | | 205 | 0 | 205 |
| 24 | 6 a. m. | 203 | 0 | 203 |
| | 6 p. m. | 283 | 0 | 283 |
| 25 | 6 a. m. | 272 | 0 | 272 |
| | 6 p. m. | 535 | 0 | 535 |
| 26 | 6 a. m. | 1,230 | 40 | 1,190 |
| | 6 p. m. | 528 | 0 | 528 |
| 27 | 6 a. m. | 1,710 | 0 | 1,710 |
| 28 | 6 p. m. | 15,800 | 900 | 14,900 |
| 29 | 12 m. | 5,800 | 700 | 5,100 |
| 30 | 12 m. | 3,240 | 400 | 2,840 |

[a] Does not include 12 square miles of drainage tributary to Cuyamaca reservoir.

*Daily discharge, in second-feet, of San Diego River at diverting dam near Lakeside, Cal., for January, 1916.*

| Date. | Total discharge, including Cuyamaca waste. | Waste, Cuyamaca reservoir. | Total discharge from 90 square miles, exclusive of Cuyamaca basin. | Date. | Total discharge, including Cuyamaca waste. | Waste, Cuyamaca reservoir. | Total discharge from 90 square miles, exclusive of Cuyamaca basin. |
|---|---|---|---|---|---|---|---|
| Jan. 1-12 | 369 | 0 | 369 | Jan. 22 | 276 | 0 | 276 |
| 13 | 36 | 0 | 36 | 23 | 205 | 0 | 205 |
| 14 | 54 | 0 | 54 | 24 | 264 | 0 | 264 |
| 15 | 147 | 0 | 147 | 25 | 509 | 11 | 498 |
| 16 | 1,581 | 0 | 1,581 | 26 | 929 | 23 | 906 |
| 17 | 4,410 | 0 | 4,410 | 27 | 10,200 | 820 | 9,380 |
| 18 | 2,655 | 33 | 2,622 | 28 | 10,900 | 1,877 | 9,023 |
| 19 | 1,815 | 106 | 1,709 | 29 | 5,910 | 815 | 5,095 |
| 20 | 727 | 106 | 621 | 30 | 3,070 | 550 | 2,520 |
| 21 | 409 | 65 | 343 | 31 | 2,227 | 345 | 1,882 |

| Total run-off for month | | |
|---|---|---|
| | acre-feet | 92,800 |
| | depth in inches on drainage area | 17.06 |

### SAN DIEGO RIVER AT CAPITAN GRANDE DAM SITE, NEAR LAKESIDE, CAL.

LOCATION.—1,000 feet upstream from the west line of sec. 8, T. 15 S., R. 2 E., in Capitan Grande Indian Reservation, about half a mile below mouth of Chocolate Creek, 1½ miles below mouth of South Fork of San Diego River, and 7¼ miles northeast of Lakeside, San Diego County.

DRAINAGE AREA.—189 square miles (measured on topographic map).

ELEVATION.—About 600 feet above sea level.

MAXIMUM DISCHARGE IN JANUARY, 1916.—J. F. Covert, chief engineer, Sweetwater Water Co., measured cross sections and slope at this point and computed the maximum discharge as follows:

FIRST SECTION.—Mean area, 2,151 square feet; mean wet perimeter, 205 feet; mean hydraulic radius, 10.5; slope, 0.0035; assumed value of $n$ in Kutter's formula, 0.03; coefficient $c$, 74; mean velocity, 14.2 feet per second.

SECOND SECTION.—Mean area, 480 square feet; mean wet perimeter, 118 feet; mean hydraulic radius, 4.1; slope, 0.0035; assumed value of $n$ in Kutter's formula, 0.035; coefficient $c$, 54; mean velocity, 6.5 feet per second.

Total discharge, 34,600 second-feet, or 183 second-feet per square mile of drainage area.

W. S. Post, consulting engineer for Cuyamaca Water Co., obtained the following flood data at approximately the same location (Pl. XI, *A*): Width, 187 feet; wet perimeter, 196 feet; area, 2,620 square feet; hydraulic radius, 13.4; slope, 0.0035 (in 1,600 feet). If the value of $n$ in Kutter's formula is assumed as 0.035 the discharge is 38,000 second-feet, or 201 second-feet per square mile of drainage area. This discharge occurred during the afternoon of January 27. The crest reached Lakeside about 2 p. m.

### SAN DIEGO RIVER NEAR SANTEE, CAL.

LOCATION.—In El Cajon grant at Mission dam, just above Oak Canyon, about half a mile below Spring Canyon, and 4½ miles west of Santee, San Diego County.

DRAINAGE AREA.—375 square miles (measured on topographic maps).

ELEVATION.—About 275 feet above sea level,.

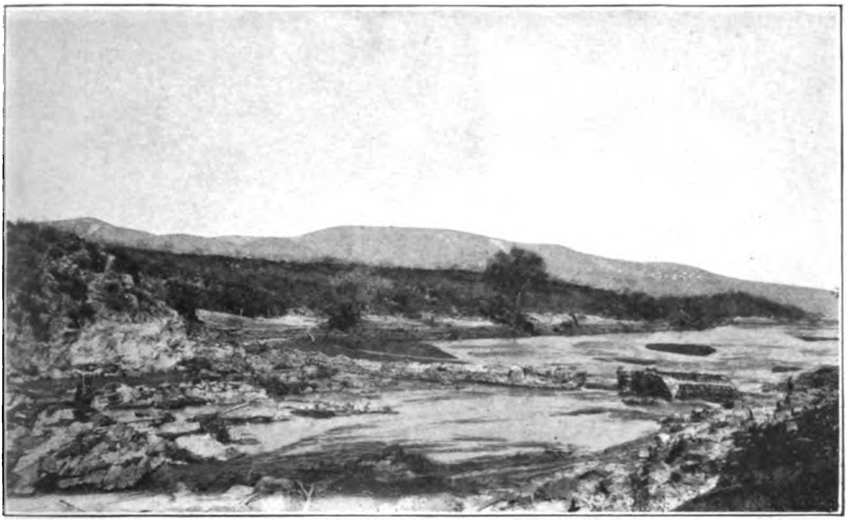
RECORDS AVAILABLE.—May 25, 1912, to January, 1916.

EXTREMES OF DISCHARGE.—1912–1915: Maximum stage recorded, 13.6 feet February 11, 1915 (discharge, 3,960 second-feet); minimum stage, dry for several months each year except for the small amount of ground water rising to the surface at the dam.

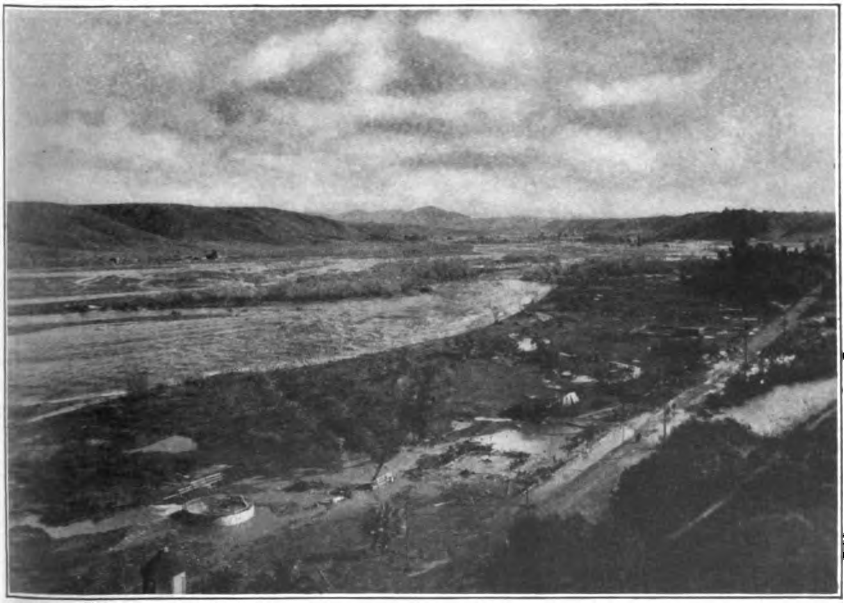
MAXIMUM DISCHARGE IN JANUARY, 1916.—On March 12, 1916, a cross section was taken 450 feet above the dam (Pl. XII, *A*). The channel, which is in sand, is straight for some distance above and below the section measured for slope. The high water removed practically all brush and trees along both banks and left the channel clean and smooth. It is believed that the remains of the old Mission dam acted as a control and prevented, at least to a considerable extent, the scour that would otherwise have occurred in the bed of the stream. On this account no allowance for scour has been made in computing the area at maximum stage.

The crest of the flood reached the gaging station during the afternoon of January 27. At Lakeside (Pl. XIII), 8½ miles upstream, it was reported that the crest occurred between 2 and 4 p. m. and at San Diego, 12½ miles downstream, at 7 p. m.

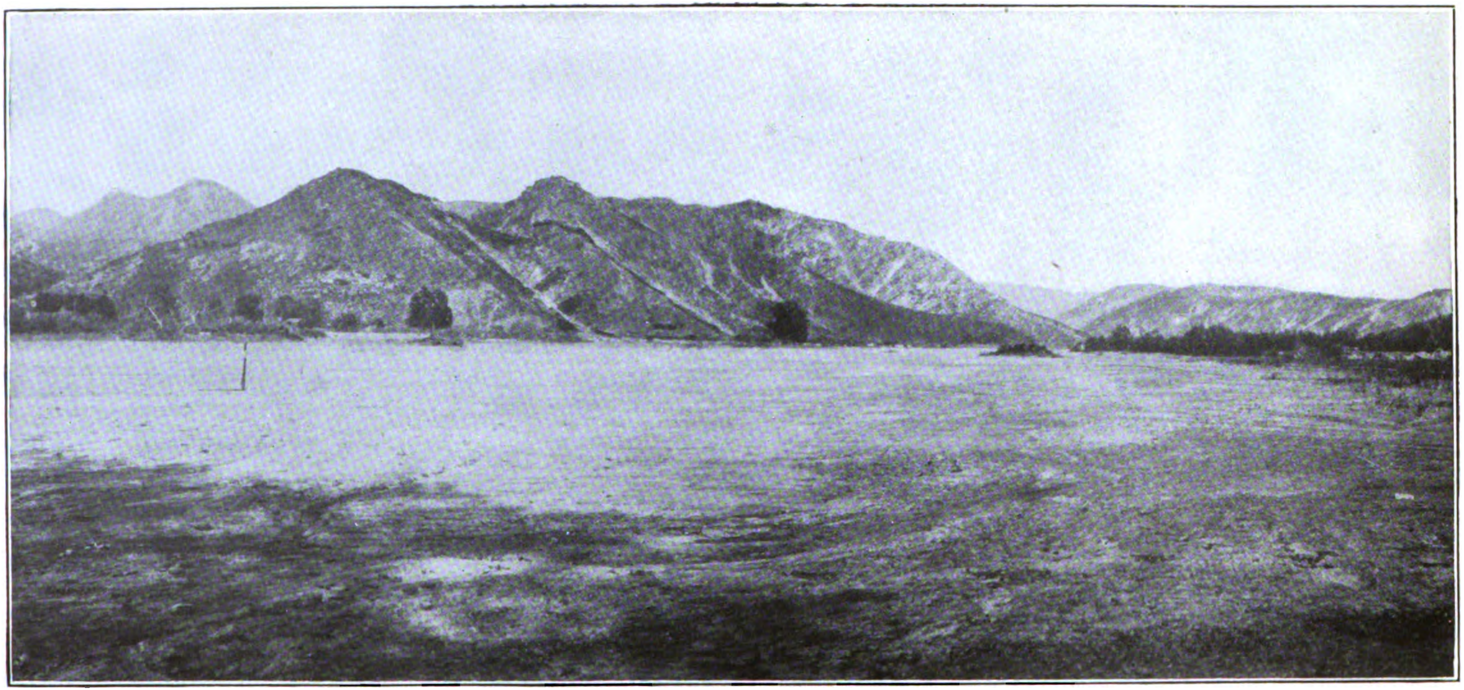
The maximum gage height at the dam was 25.1 feet (291.5 feet above sea level). The discharge is estimated as follows: Width, 310 feet; wet perimeter, 320 feet; area, 4,200 square feet; hydraulic radius, 13.1; slope of water surface on March 12, 1916, 0.0037 (for 875 feet). If the value of $n$ in Kutter's formula is assumed as 0.03, the discharge was 70,200 second-feet, or 187 second-feet per square mile of drainage area.



*A.* VIEW UP SAN DIEGO RIVER AT MISSION DAM, NEAR SANTEE, AFTER FLOOD OF JANUARY, 1916.



*B.* VIEW UP MISSION VALLEY, SAN DIEGO RIVER, FROM OLD MUNICIPAL PUMPING PLANT, AFTER FLOOD OF JANUARY 1916.



VIEW UP CHANNEL OF SAN DIEGO RIVER AT LAKESIDE, AFTER FLOOD OF JANUARY, 1916.

**Measurements** of cross sections and slope, above and below Mission dam, made by J. F. Covert, engineer, Sweetwater Water Co., were used by F. C. Finkle, consulting engineer, to compute the maximum discharge, with the following results:

*At Mission dam.*—Mean area, 5,272 square feet; mean wet perimeter, 390 feet; mean hydraulic radius, 13.5; slope, 0.0027; assumed value of *n* in Kutter's formula, 0.03; coefficient *c*, 76.9; mean velocity, 14.7 feet per second; discharge, 77,390 second-feet.

*Two miles below Mission dam.*—Mean area, 4,884 square feet; mean wet perimeter, 286 feet; mean hydraulic radius, 17.1; slope, 0.0031; assumed value of *n* in Kutter's formula, 0.035; coefficient *c*, 69.7; mean velocity, 16.1 feet per second; discharge, 78,510 second-feet.

### SAN DIEGO RIVER AT SAN DIEGO, CAL.

**Location.**—At highway bridge in Block 391, Old Town subdivision, city of San Diego, San Diego County, and about 1½ miles above mouth (Pl. VII, *A*).

**Drainage area.**—434 square miles (measured on topographic maps); 431 square miles at Murray Canyon ford, 2 miles upstream.

**Elevation.**—Practically sea level.

**Records available.**—October 1, 1912, to January, 1916.

**Gage.**—Inclined staff on left bank at bridge.

**Discharge measurements.**—Made from concrete highway bridge until its failure at 2.20 p. m., January 27, 1916; after this date at the Atchison, Topeka & Santa Fe Railway bridge, a short distance below.

**Channel and control.**—Composed of sand; shifting.

**Extreme of discharge.**—1912–1915: Maximum stage recorded, 16.61 feet February 21, 1914 (approximate discharge, 9,500 second-feet); minimum stage, dry for several months during each year.

**Maximum discharge in January, 1916.**—The crest of the second flood occurred at 7 p. m., January 27. The discharge was estimated as 75,000 second-feet, or 173 second-feet per square mile.

**Accuracy.**—On account of the shifting of the channel, the gage height record for periods not covered by discharge measurements is of little value. Daily discharge reported was computed from a hydrograph drawn through the discharge measurements and conforming in general shape with that determined for San Luis Rey River at Oceanside. The crest discharge on January 27, 1916, was estimated from the computed maximum discharge at Mission dam. Results considered fair.

*Discharge measurements of San Diego River at San Diego, Cal., during January, 1916.*

| Date. | | Made by— | Gage height. | Discharge. | Remarks. | |
|---|---|---|---|---|---|---|
| | | | | | Time of measurement. | Method. |
| | | | *Feet.* | *Sec.-ft.* | | |
| Jan. | 17 | R. W. Day | 13.55 | 10,400 | 9 a. m. | Floats. |
| | 17 | ....do | 13.45 | 10,100 | 10 a. m. | Do. |
| | 18 | ....do | 13.34 | 7,380 | 3 p. m. | Do. |
| | 19 | Ellis and McFadden | 12.1 | 8,650 | Noon | Do. |
| | 20 | ....do | 9.1 | 2,180 | 11 a. m. | Do. |
| | 21 | W. D. McFadden | 7.8 | 1,820 | Noon | Meter. |
| | 22 | ....do | 7.1 | 1,270 | ...do | Do. |
| | 28 | Ellis and Day | 9.9 | 11,100 | 9 a. m. | Floats. |
| | 29 | R. W. Day | 9.98 | 6,560 | 11 a. m. | Do. |

NOTE.—Mean velocities taken as 85 per cent of surface velocities obtained from floats.

*Gage height, in feet, and discharge, in second-feet, of San Diego River at San Diego, Cal., for January, 1916.*

| Date. | Time. | Gage height. | Discharge. | Mean daily discharge. |
|---|---|---|---|---|
| Jan. 1–16 | | | | Dry. |
| 17 | 9.30 a. m. | 13.5 | 10,200 | 13,400 |
| | 12 p. m. | 13.85 | 32,000 | |
| 18 | 3 p. m. | 13.34 | 7,380 | 12,700 |
| 19 | 12 m. | 12.1 | 8,650 | 7,320 |
| 20 | 11 a. m. | 9.1 | 2,180 | 2,550 |
| 21 | 12 m. | 7.8 | 1,820 | 1,760 |
| 22 | 12 m. | 7.1 | 1,270 | 1,310 |
| 23 | 12 m. | 7.3 | 1,400 | 1,380 |
| 24 | 10 a. m. | 7.2 | 1,330 | 1,260 |
| 25 | 11 a. m. | 6.9 | 1,130 | 1,280 |
| 26 | 11 a. m. | 8.0 | 2,600 | 3,000 |
| | 4 p. m. | 8.1 | 3,000 | |
| 27 | 7 a. m. | 12.0 | 18,200 | 38,000 |
| | 3.30 p. m. | 17.3 | 59,500 | |
| | 7 p. m. | 19.3 | 75,000 | |
| 28 | 9 a. m. | 9.9 | 11,100 | 13,200 |
| 29 | 11 a. m. | 9.98 | 6,560 | 5,980 |
| 30 | | | | 2,750 |
| 31 | | | | 1,280 |

| Total run-off for month | |
|---|---|
| acre-feet | 213,000 |
| depth in inches on drainage area | 9.19 |

NOTE.—Water began flowing early in morning, Jan. 17; crest of first flood at midnight Jan. 17; crest of second flood at 7 p. m., Jan. 27. Concrete highway bridge failed at 2.20 p. m. Jan. 27.

### BOULDER CREEK AT CUYAMACA RESERVOIR, NEAR JULIAN, CAL.

LOCATION.—In Cuyamaca grant, 12 miles above junction with San Diego River, and 7 miles south of Julian, San Diego County.

DRAINAGE AREA.—12 square miles, including area of reservoir, which is about 1 square mile (measured on topographic map).

ELEVATION.—About 4,650 feet above sea level.

RECORDS AVAILABLE.—June 19, 1912, to January, 1916. Records show only the amount of stored water released to supply San Diego flume.

RESERVOIR.—Cuyamaca dam, completed in 1886, was one of the first earth dams built in California for irrigation storage. The height, as originally constructed, was 35 feet. In 1894 the dam was enlarged, increasing the capacity of the reservoir to 11,400 acre-feet. The present dam is 635 feet long and 41½ feet high, having an upstream slope of 2:1 and a downstream slope of 1½:1. The water released from the reservoir flows down the natural channel of Boulder Creek and San Diego River to the intake of San Diego flume.

**Flood discharge January, 1916.**—W. S. Post, consulting engineer for Cuyamaca Water Co., computed the run-off, from the 11 square miles of drainage area tributary to the reservoir, for January 13 to 31, 1916. The estimates, which follow, are based upon very complete reports which give elevation of water surface in the reservoir, spillway discharge, rainfall records, etc.

*Discharge, in second-feet, of Boulder Creek at Cuyamaca reservoir, near Julian, Cal., for January, 1916.*

| Date. | | Hour. | Instantaneous discharge from 11 square miles.[a] | Instantaneous discharge per square mile. | Total discharge from 11 square miles. |
|---|---|---|---|---|---|
| Jan. | 13 | 6 p. m. | 3 | ........ | 3 |
| | 14 | 6 p. m. | 59 | 5 | 59 |
| | 15 | 6 p. m. | 125 | 11 | 125 |
| | 16 | 6 p. m. | 534 | 48 | 534 |
| | 17 | 6 p. m. | 865 | 79 | 865 |
| | 18 | 6 p. m. | 456 | 41 | 456 |
| | 19 | 6 p. m. | 0 | ........ | 0 |
| | 20 | 6 p. m. | 0 | ........ | 0 |
| | 21 | 6 p. m. | 20 | 2 | 20 |
| | 22 | 6 p. m. | 39 | 3 | 39 |
| | 23 | 6 p. m. | 32 | 3 | 32 |
| | 24 | 6 p. m. | 29 | 3 | 29 |
| | 25 | ........ | 0 | ........ | 0 |
| | 26 | 6 p. m. | 715 | 65 | 715 |
| | 27 | 8 a. m. | 1,825 | 166 | 2,100 |
| | | 10 a. m. | 1,671 | 152 | ........ |
| | | 6 p. m. | 2,393 | 217 | ........ |
| | 28 | 6 a. m. | 1,126 | 102 | 823 |
| | | 6 p. m. | 383 | 35 | ........ |
| | 29 | 6 a. m. | 380 | 35 | 153 |
| | | 6 p. m. | 200 | 17 | ........ |
| | 30 | 6 a. m. | 137 | 12 | 137 |
| | | 6 p. m. | 88 | 8 | ........ |
| | 31 | 6 a. m. | 100 | 9 | 120 |
| | | 6 p. m. | 95 | 9 | ........ |

[a] Does not include precipitation on reservoir area, which is about 1 square mile.

| Total run-off for month | | |
|---|---|---|
| | acre-feet | 12,300 |
| | depth in inches on drainage area | 19.22 |

### SAN VICENTE CREEK AT FOSTER, CAL.

**Location.**—In sec. 31, T. 14 S., R. 1 E., about three-eighths of a mile above Foster, San Diego County, and 3¾ miles above junction with San Diego River.

**Drainage area.**—74.9 square miles (measured on topographic map).

**Elevation.**—About 500 feet above sea level.

**Records available.**—January 29 to April 4, 1915.

**Extremes of discharge.**—1915: Maximum stage recorded, 6.5 feet February 11, 1915 (discharge, 1,190 second-feet); minimum stage, dry for several months during the year.

**Maximum discharge January, 1916.**—On March 15, 1916, a cross section was measured 600 feet above abandoned gaging station (Pl. XI, *B*). The bed is composed of sand, fine gravel, and small boulders; channel clean except for trees and brush that grow along banks near the high water mark. The water was over the highway on left bank at the point where the cross-section was taken. The high-water slope was found to be 2.44 feet in 685 feet, which was somewhat less than the slope of the present water surface, owing probably to the slight contraction of the channel and curvature below. The channel is practically straight for the distance covered by the slope data.

The maximum discharge, which occurred January 27, is estimated as follows: Width, 190 feet; wet perimeter, 198 feet; area, 1,940 square feet; high water slope, .0036. If the value of *n* in Kutter's formula is assumed as .045, the discharge is 18,600 second-feet, or 248 second-feet per square mile of drainage area.

### SWITZER CANYON AT SAN DIEGO, CAL.

The following information was furnished by Mr. George Cromwell, city engineer, San Diego, Cal.:

The drainage area of this stream above the point of measurement is 3.55 square miles: 1 square mile lies within the City Park and, except for a small part under cultivation, is in its original state as rough land covered with brush; and 2.55 square miles comprise subdivided residence property with graded streets. The maximum rate of run-off, which occurred at 7 a. m., January 27, 1916, was 668.5 second-feet, or 188 second-feet per square mile.

## SAN DIEGUITO RIVER BASIN.

### GENERAL FEATURES.

San Dieguito River, or Santa Ysabel Creek, as it is known from its source to the San Pasqual Valley, rises in the Volcan Mountains on the western slope of the Coast Range and flows westward through San Pasqual Valley, below which it takes its true name, and discharges into the Pacific Ocean midway between Oceanside and San Diego. Its length is 50 miles, and the maximum width of the drainage basin about 15 miles. The total drainage area is approximately 340 square miles. It lies south of San Luis Rey River and north of the San Diego River basin.

Numerous small tributaries enter Santa Ysabel Creek from its source to San Pasqual Valley, the most important being Black Canyon and Temescal creeks from the north and Santa Maria Creek from the south. Above the San Pasqual Valley the creek maintains a light flow throughout the year, but below that point the channel is dry during the summer months.

The upper part of the basin is rough, the surface being cut by many canyons. The lower part in the foothills is more rolling, with large areas of valley and high mesa land. The formation is a loose granite. The basin has very little timber, the principal cover being brush, grass, and a few scattered oaks.

The mean annual rainfall ranges from 10 to 15 inches along the foothills and from 20 to 40 inches in the mountains.

### SANTA YSABEL CREEK NEAR MESA GRANDE, CAL.

LOCATION.—In the NW. ¼ sec. 21, T. 12 S., R. 2 E., at Sutherland dam site, about 1 mile below Sutherland, 1½ miles above mouth of Black Canyon Creek, and 4½ miles southwest of Mesa Grande, San Diego County.

DRAINAGE AREA.—53.4 square miles (measured on topographic map).

ELEVATION.—About 1,900 feet above sea level.

RECORDS AVAILABLE.—December 29, 1912, to January, 1916.

GAGE.—Friez water-stage recorder on right bank just above dam site; instrument was removed by flood January 27.

DISCHARGE MEASUREMENTS.—Made from cable at gage or by wading; equipment destroyed by the January flood.

**Channel and control.**—Shifting sand above and below station. A concrete control was constructed at an outcropping of bedrock 20 feet below gage. Banks are high, covered with brush, and not likely to be overflowed. Zero flow occurs at zero gage height.

**Extremes of discharge.**—1912-1915: Maximum stage recorded, 4.53 feet February 11, 1915 (discharge, 1,040 second-feet); minimum stage dry October 1 and 2, 1913, August 12 to 29 and September 6 to 13, 1914.

**Maximum discharge in January, 1916.**—The maximum stage was 11.0 feet at noon January 27. Measurements of cross-section and slope made a short distance above Ramona-Mesa Grande highway bridge (Pl. XIV, *A*) and about a mile below gaging station on May 23, 1916, were furnished by W. S. Post, consulting engineer for Volcan Land & Water Co., as follows: Area, 1,180 square feet; wet perimeter, 149 feet; hydraulic radius, 7. 9; high water slope from 500 feet above cross-section to 500 feet below, 0. 02; width, 144 feet. If the value of *n* in Kutter's formula is assumed as 0. 5 (channel composed of boulders and is rough), the discharge is 21,100 second-feet, or 395 second-feet per square mile of drainage area.

**Accuracy.**—Results during flood period are considered fair. Water-stage recorder was in operation January 1 to 15 and 22 to 27. For the remainder of the month the staff gage was read once or twice daily.

The following discharge measurement was made by W. J. Isbell:

January 11, 1916: Gage-height, 1. 04 feet; discharge, 35 second-feet.

*Discharge, in second-feet, of Santa Ysabel Creek near Mesa Grande, Cal., for January, 1916.*

| Date. | Maximum. | Minimum. | Mean. | Date. | Maximum. | Minimum. | Mean. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | | | 4 | Jan. 17 | 10,600 | 1,550 | 4,130 |
| 2 | | | 10 | 18 | 6,500 | 2,500 | 4,200 |
| 3 | | | 12 | 19 | 3,660 | 1,940 | 2,580 |
| 4 | | | 9 | 20 | 1,940 | 650 | 1,280 |
| 5 | | | 10 | 21 | | | 500 |
| 6 | | | 10 | 22 | | | 480 |
| 7 | | | 9.5 | 23 | | | 225 |
| 8 | | | 8 | 24 | | | 200 |
| 9 | | | 18 | 25 | 660 | 200 | 416 |
| 10 | | | 62 | 26 | 460 | 350 | 406 |
| 11 | | | 45 | 27 | 21,100 | 400 | 10,800 |
| 12 | | | 19 | 28 | 8,550 | 2,400 | 4,720 |
| 13 | | | 15 | 29 | 2,400 | 1,000 | 1,520 |
| 14 | | | 36 | 30 | | | 800 |
| 15 | | | 54 | 31 | | | 560 |
| 16 | 1,750 | 50 | 405 | | | | |

| Total run-off for month | |
|---|---|
| acre-feet | 66,400 |
| depth in inches on drainage area | 23.29 |

### SANTA YSABEL CREEK NEAR RAMONA, CAL.

**Location.**—In the NE. ¼ sec. 27, T. 12 S., R. 1 E., at Pamo Camp, 1 mile below mouth of Temescal Creek, and about 4 miles north of Ramona, San Diego County.

**Drainage area.**—110 square miles (measured on topographic map).

**Elevation.**—About 925 feet above sea level.

**Records available.**—February 5, 1912, to January, 1916.

**Gage.**—Staff in four sections on left bank, with a short vertical section at concrete control for use during extreme low water. Read three times a day and more frequently during high water. Destroyed by high water January 16. Observations for the remainder of the month were made by setting stakes at water surface and later referring them to gage datum by leveling. New staff was installed January 31 at proposed dam site about half a mile down stream.

**Discharge measurements.**—Made from cable at gage or by wading. Cable was washed out on January 17, reinstalled January 26, and again destroyed January 27.

**Channel and control.**—Composed of sand and some boulders; somewhat shifting. On November 19, 1912, a concrete control was built about 30 feet below gage. The floods January 17 and 27, 1916, formed an entirely new channel to left of control.

**Extremes of discharge.**—1912–1915: Maximum stage recorded, 8.05 feet, February 11, 1915 (discharge, 3,330 second-feet); minimum stage, 0.74 foot, October 1 to 6, 1915 (discharge, 0.1 second-foot).

**Maximum discharge in January, 1916.**—Measurements of cross section and slope data were made March 14, 1916, about half a mile below gaging station (Pl. XIV, *B*). The channel, which is composed of large boulders, gravel, and sand, is a little rough, and is clean, except for a few small willows. It is slightly curved between points covered by slope data. The maximum discharge, which occurred at 7 p. m. January 27, has been computed as follows: Width, 271 feet; wet perimeter, 276 feet; area, 2,070 square feet; hydraulic radius, 7.5; slope of present water surface, 0.0067 (for 455 feet). If the value of $n$ in Kutter's formula is assumed as 0.035, the discharge is 28,400 second-feet, or 258 second-feet per square mile of drainage area.

The crest of the flood at 9 p. m., January 17, estimated from the Mesa Grande record, was 14,300 second-feet.

**Accuracy.**—Results considered approximate. The gage-height records January 1 to 15 were lost during the flood. Discharge for this period estimated from Mesa Grande record and hydrographer's notes. Discharge January 16 to 30 computed from a hydrograph defined by discharge measurements and computed discharge, and having the general shape of the hydrograph for Santa Ysabel Creek near Mesa Grande.

*Discharge measurements of Santa Ysabel Creek near Ramona, Cal., for January and February, 1916.*

| Date. | Made by— | Gage height. | Discharge. | Date. | Made by— | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Sec.-ft.* | | | *Feet.* | *Sec.-ft.* |
| Jan. 11 | W. J. Isbell | 1.83 | 69 | Feb. 1 | W. D. McFadden | 4.80 | [a] 742 |
| 26 | W. D. McFadden | 2.50 | 531 | | | | |

[a] Float measurement.

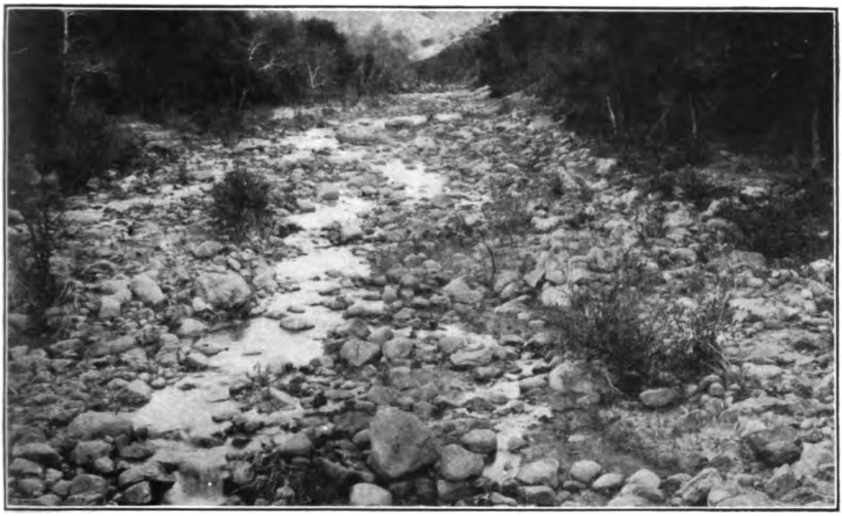
*Mean daily discharge, in second-feet, of Santa Ysabel Creek near Ramona, Cal., for January, 1916.*

| Day. | Discharge. | Day. | Discharge. | Day. | Discharge. | Day. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 7 | Jan. 9 | 28 | Jan. 17 | 6,060 | Jan. 25 | 668 |
| 2 | 17 | 10 | 95 | 18 | 7,420 | 26 | 611 |
| 3 | 20 | 11 | 69 | 19 | 3,680 | 27 | 14,100 |
| 4 | 15 | 12 | 29 | 20 | 2,110 | 28 | 9,740 |
| 5 | 17 | 13 | 23 | 21 | 865 | 29 | 2,540 |
| 6 | 17 | 14 | 55 | 22 | 560 | 30 | 1,160 |
| 7 | 15 | 15 | 81 | 23 | 450 | 31 | 865 |
| 8 | 12 | 16 | 664 | 24 | 400 | | |

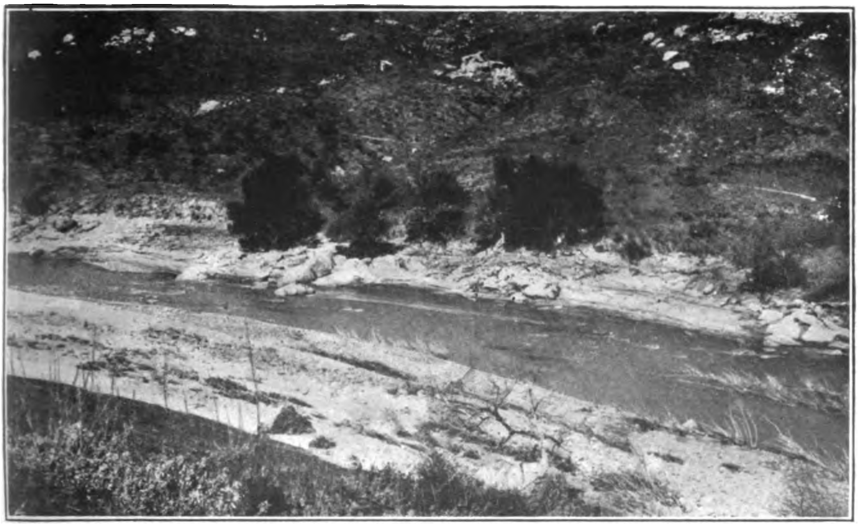
| Total run-off for month | | |
|---|---|---|
| | acre-feet | 104,000 |
| | depth in inches on drainage area | 17.75 |

## SAN DIEGUITO RIVER NEAR BERNARDO, CAL.

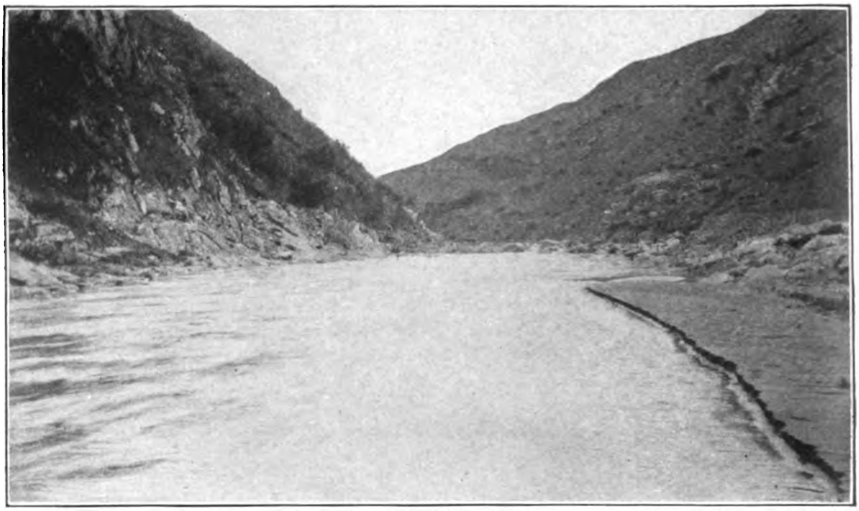
**Location.**—In the SE. ¼ NW. ¼ sec. 18, T. 13 S., R. 2 W., at Carroll dam site, 5½ miles downstream from former station at Bernardo bridge, about 10½ miles above mouth of river, and 4 miles southwest of Bernardo, San Diego County.



*A.* VIEW UPSTREAM ON SANTA YSABEL CREEK NEAR MESA GRANDE, AFTER FLOOD OF JANUARY, 1916.



*B.* VIEW ACROSS SANTA YSABEL CREEK NEAR RAMONA, AFTER FLOOD OF JANUARY, 1916.



*A.* VIEW DOWNSTREAM ON SAN DIEGUITO RIVER AT CARROLL DAM SITE, NEAR BERNARDO, AFTER FLOOD OF JANUARY, 1916.

*B.* VIEW DOWNSTREAM ON SANTA MARIA CREEK NEAR RAMONA, IN 1917.

**Drainage area.**—299 square miles (measured on topographic maps); 266 square miles for station at Bernardo.

**Elevation.**—About 150 feet above sea level.

**Records available.**—April 17, 1912, to September 30, 1915, for station at Bernardo.

**Gage.**—Vertical staff in 4 sections on right bank at dam site.

**Discharge measurements.**—Equipment not yet installed. Wading measurements have been made at gage.

**Channel and control.**—Shifting sand with bed rock outcropping about 400 feet below gage (Pl. XV, *A*).

**Extremes of discharge.**—1912–1915: Maximum stage recorded, 17.8 feet February 11, 1915 (discharge, 5,050 second-feet); minimum stage, practically dry for several months each year (for Bernardo station).

**Maximum discharge in January, 1916.**—The maximum stage was reported as 21.2 feet and occurred at from 1 p. m. to 3 p. m. January 27. Measurements of slope and two cross sections made at the dam site were furnished by W. S. Post, consulting engineer for Volcan Land & Water Co., as follows: Mean area, 4,870 square feet (correction was made for scour in channel as a profile of the bed rock was available); mean hydraulic radius, 17.25; high-water slope, 0.0033 (for 705 feet). If the value of *n* in Kutter's formula is assumed as 0.04, the discharge is 72,100 second-feet, or 241 second-feet per square mile of drainage area.

**Accuracy.**—Discharge January 1 to 16 computed from records obtained at station at Bernardo. On January 17 the equipment at this station was destroyed and the channel greatly changed by the high water. For January 17 to 31, discharge record at Carroll dam site has been furnished by W. S. Post. These computations are based upon the gage-height record and rating curves defined by later measurements and flood discharge computed from data on cross section and slope. Mean daily discharge computed from hydrograph defined by these data and conforming in general shape to the hydrographs for other stations in the same and adjoining drainage basins.

*Mean daily discharge, in second-feet, of San Dieguito River near Bernardo, Cal., for January, 1916.*

| Day. | Discharge. | Day. | Discharge. | Day. | Discharge. | Day. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 22 | Jan. 9 | 32 | Jan. 17 | 11,800 | Jan. 25 | 1,060 |
| 2 | 22 | 10 | 45 | 18 | 27,000 | 26 | 2,950 |
| 3 | 27 | 11 | 257 | 19 | 14,800 | 27 | 37,200 |
| 4 | 22 | 12 | 100 | 20 | 5,220 | 28 | 15,100 |
| 5 | 22 | 13 | 82 | 21 | 1,730 | 29 | 4,750 |
| 6 | 32 | 14 | 74 | 22 | 909 | 30 | 2,200 |
| 7 | 32 | 15 | 230 | 23 | 662 | 31 | 1,220 |
| 8 | 32 | 16 | 1,310 | 24 | 708 | | |

Total run-off for month {acre-feet ........ 257,500
Total run-off for month {depth in inches on drainage area ........ 16.14

**Note.**—Discharge, Jan. 1–16, is for former station at Bernardo. The run-off for this period for the area between Bernardo bridge and Carroll dam site is believed to be negligible.

### SANTA MARIA CREEK NEAR RAMONA, CAL.

**Location.**—In the SE. ¼ sec. 11, T. 13 S., R. 1 W., about 7 miles below mouth of Hatfield Creek, and 5½ miles west of Ramona, San Diego County.

**Drainage area.**—57.3 square miles (measured on topographic map).

**Elevation.**—About 1,300 feet above sea level.

**Records available.**—November 6, 1912 to January, 1916.

**Gage.**—Friez water-stage recorder on right bank just above concrete control, with staff in two sections on opposite bank. Water-stage recorder was destroyed by January flood.

**Discharge measurements.**—Made from cable 100 feet below gage or by wading; equipment was destroyed by the January flood.

**Channel and control.**—Shifting sand above and below station. Concrete control installed just below gage at an outcropping of solid rock. Zero flow occurs at a gage height of about 1.32 feet.

About 1,000 feet below gage, valley narrows to a rocky gorge at proposed dam site. There appears to be considerable natural storage in the channel at extreme high water. The slope of the water surface at maximum flood stage was found to be much less than at low or medium discharge.

**Extremes of discharge.**—1912-1915: Maximum stage recorded, 7.05 feet February 10, 1915 (discharge 1,890 second-feet); minimum stage, dry for several months each year.

**Maximum discharge in January, 1916.**—Measurements of slope and cross section were made at the gaging station (Pl. XV, *B*) on March 14, 1916. The cross section was taken 315 feet below staff gage. The channel, which is composed principally of sand, is straight and clean except for a few trees on left bank below gage. About 1,000 feet below station valley narrows to a rock gorge which causes some natural storage in the channel during flood stages. The maximum gage height, as determined from flood marks, was 15.9 feet and occurred at about 5 p. m. January 27. The maximum discharge has been computed as follows: Width, 238 feet; wet perimeter, 242 feet; area, 2,040 square feet; hydraulic radius, 8.4; slope of water surface at maximum stage, 0.00037 (for 1,010 feet). The slope of the water surface March 14 was 0.0059 (for 575 feet). If the value of *n* in Kutter's formula is assumed as 0.035, the discharge is 7.140 second-feet, or 125 second-feet per square mile or drainage area.

**Accuracy.**—Results considered reliable. Gage was read two to six times a day during high water. The concrete control was not injured by the flood.

*Discharge measurements of Santa Maria Creek near Ramona, Cal., for January and February, 1916.*

| Date. | Made by— | Gage height. | Discharge. | Date. | Made by— | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Sec.-ft.* | | | *Feet.* | *Sec.-ft.* |
| Jan. 4 | W. J. Isbell | 1.37 | 0.1 | Jan. 24 | W. D. McFadden | 2.70 | 75 |
| 11 | do | 1.80 | 2.4 | Feb. 3 | Day and McFadden | 3.45 | 144 |

*Discharge, in second-feet, of Santa Maria Creek near Ramona, Cal., for January, 1916.*

| Date. | Maximum. | Minimum. | Mean. | Date. | Maximum. | Minimum. | Mean. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | | | 0.2 | Jan. 17 | 3,720 | 2,210 | 2,820 |
| 2 | | | .2 | 18 | 3,310 | 1,280 | 1,960 |
| 3 | | | .2 | 19 | 1,280 | 518 | 914 |
| 4 | | | .0 | 20 | 518 | 178 | 283 |
| 5 | | | .0 | 21 | 178 | 150 | 163 |
| 6 | | | .0 | 22 | 150 | 90 | 113 |
| 7 | | | .0 | 23 | 90 | 71 | 78 |
| 8 | | | .2 | 24 | 71 | 71 | 71 |
| 9 | | | .2 | 25 | 816 | 71 | 275 |
| 10 | | | .4 | 26 | 3,360 | 816 | 1,970 |
| 11 | | | 2.4 | 27 | 7,140 | 2,880 | 4,960 |
| 12 | | | 1.5 | 28 | 2,880 | 430 | 1,370 |
| 13 | | | 1.0 | 29 | 430 | 112 | 223 |
| 14 | | | 2.5 | 30 | 410 | 208 | 322 |
| 15 | | | 4.0 | 31 | 208 | 136 | 150 |
| 16 | | | 1,200 | | | | |

Total run-off for month {acre-feet ........ 33,500
{depth in inches on drainage area ........ 10.96

Note.—Discharge January 4 to 7 less than 0.1 second-foot.

## SAN LUIS REY RIVER BASIN.

### GENERAL FEATURES.

San Luis Rey River drains an area comprising 565 square miles lying wholly in the northern part of San Diego County and extending from the crest of the Coast Range to the Pacific Ocean, a distance of 65 miles, with a maximum width of about 16 miles.

The river is formed by many small streams which rise in the higher elevations of the Coast Range and come together at the lower or west end of what is known as Warner's valley. Below this point the river flows for a distance of 10 miles through a deep narrow canyon with a heavy grade, then over a sandy and gravelly bed with medium grade for some 40 miles, finally discharging into the Pacific Ocean at Oceanside.

Altitudes within this basin range from 50 to 500 feet in the foothills in the vicinity of Oceanside and from 500 to 6,000 feet on the mountains. Palomar Mountain, the highest peak in the basin, is 6,126 feet above sea level. The upper portion of the basin is more or less rolling, and several of the valleys are under cultivation and are used extensively for stock raising; the middle part, occupied by the river in its canyon, is rough; on the lower reaches the surface becomes less rugged, merging into the foothills, which extend to the coast. The rocks are granitic.

The basin is poorly forested. Some fairly good timber is found on the higher elevations, but the greater part of the cover is brush and grass with a scattered growth of oaks.

The mean annual precipitation in this basin ranges from about 10 to 50 inches, gradually increasing with altitude. It occurs almost entirely as rain, snow appearing only occasionally on the high elevations.

### SAN LUIS REY RIVER NEAR MESA GRANDE, CAL.

**Location.**—In the NE. ¼ sec. 9, T. 11 S., R. 2 E., 1 mile below Warner dam site and mouth of Carrizo Creek, and about 5 miles north of Mesa Grande, San Diego County.

**Drainage area.**—209 square miles (measured on topographic and military survey maps).

**Elevation.**—About 2,650 feet above sea level.

**Records available.**—October 3, 1911 to January 1916.

**Gage.**—Barrett & Lawrence water-stage recorder on left bank just above concrete weir; destroyed by high water during night, January 16, 1916. Staff gage at same location and datum as water-stage recorder read frequently January 17 to 31 by an engineer of the Volcan Land & Water Co.

**Discharge measurements.**—Made from cable about a mile above gage or by wading.

**Channel and control.**—Composed of sand and gravel; somewhat shifting. The concrete weir which acted as a control was practically destroyed by the high water.

**Extremes of discharge.**—1911–1915: Maximum stage recorded, 7.5 feet February 21, 1914 (discharge 3,470 second-feet); minimum stage, 0.09 foot August 31, 1914 (discharge, estimated, 0.2 second-foot).

**Maximum discharge in January, 1916.**—Measurements of cross sections and slope made a short distance below dam site, were furnished by W. S. Post, consulting engineer, for Volcan Land & Water Co., as follows:

Mean area, 2,960 square feet; mean wet perimeter, 242 feet; mean hydraulic radius, 12.2; high water slope over 900-foot range (from 300 feet above to 600 feet below cable), 0.0073. If the value of *n* in Kutter's formula is assumed as 0.035, the discharge is 58,600 second-feet, or 280 second-feet per square mile of dranage area. No correction was made to the area for probable scour in channel at crest of flood.

ACCURACY.—Results considered good. Gage read frequently except during night.

*Discharge measurements of San Luis Rey River near Mesa Grande, Cal., during January, 1916.*

Made by W. J. Isbell.

| Date. | Gage height. | Discharge. | Time of measurement. | Date. | Gage height. | Discharge. | Time of measurement. |
|---|---|---|---|---|---|---|---|
| | *Feet.* | *Sec-ft.* | | | *Feet.* | *Sec-ft.* | |
| Jan. 1 | 0.35 | 16 | .......... | Jan. 18 | 9.06 | [a] 9,850 | 11 a. m. |
| 3 | .42 | 24 | 9 a. m. | 19 | 5.44 | 2,630 | 3 p. m. |
| 7 | .39 | 21 | 4 p. m | 23 | 1.78 | 364 | 11 a. m. |
| 9 | .85 | 103 | 11 a. m | 26 | 2.38 | [a] 561 | 10 a. m. |
| 16 | 1.58 | 248 | 11 a. m | 28 | 6.70 | [a] 3,830 | 11 a. m. |

[a] Made from cable.

*Discharge, in second-feet, of San Luis Rey River near Mesa Grande, Cal., for January, 1916.*

| Date. | Maximum. | Minimum. | Mean. | Date. | Maximum. | Minimum. | Mean. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | | | 16 | Jan. 17 | 24,400 | 4,800 | 13,000 |
| 2 | | | 25 | 18 | 15,600 | 4,350 | 10,100 |
| 3 | | | 24 | 19 | 4,350 | 1,580 | 2,740 |
| 4 | | | 20 | 20 | 1,580 | 595 | 896 |
| 5 | | | 29 | 21 | 595 | 478 | 536 |
| 6 | | | 36 | 22 | 478 | 390 | 428 |
| 7 | | | 21 | 23 | 390 | 325 | 352 |
| 8 | | | 16 | 24 | 425 | 325 | 354 |
| 9 | | | 103 | 25 | 1,190 | 355 | 775 |
| 10 | | | 40 | 26 | 1,990 | 425 | 806 |
| 11 | | | 42 | 27 | 58,600 | 1,990 | 28,100 |
| 12 | | | 43 | 28 | 21,700 | 2,130 | 6,130 |
| 13 | | | 44 | 29 | 3,200 | 1,630 | 2,060 |
| 14 | | | 46 | 30 | 2,770 | 1,160 | 1,610 |
| 15 | | | 170 | 31 | 1,160 | 895 | 1,020 |
| 16 | 5,300 | 210 | 1,550 | | | | |

| Total run-off for month | | |
|---|---|---|
| | acre-feet | 141,000 |
| | depth in inches on drainage area | 12.68 |

NOTE.—Crest of flood Jan. 17 occurred at 1.45 p. m., gage height 12.8 feet; January 27 at 4.30 p. m., gage height 18.0 feet.

## SAN LUIS REY RIVER NEAR NELLIE, CAL.

LOCATION.—In Potrero Indian Reservation (near west line of sec. 33, T. 10 S., R. 1 E., unsurveyed), 500 feet above intake of Escondido Mutual Water Co.'s canal, 8 miles below gaging station at Warner dam site near Mesa Grande, and about 4½ miles southwest of Nellie, San Diego County.

DRAINAGE AREA.—240 square miles (measured on topographic and military-survey maps).

ELEVATION.—About 1,800 feet above sea level.

GAGE.—Friez water-stage recorder on left bank, with reinforced concrete well, 500 feet above intake of Escondido Mutual Water Co.'s canal; equipment destroyed by January flood.

DISCHARGE MEASUREMENTS.—Made from cable 400 feet above gage or by wading; equipment destroyed by January flood.

**Channel and control.**—Composed of sand and boulders overlying solid rock. A concrete control, extending to bedrock, was built across channel about 30 feet below gage.

**Accuracy.**—Record for January considered approximate. No gage-height record available, except January 1 to 8, as water-stage recorder was destroyed by the flood. Discharge January 9 to 14 estimated from Mesa Grande record, that for rest of month estimated from flood studies at Mesa Grande, records at Oceanside, and mean rainfall computed for drainage area.

*Discharge measurements of San Luis Rey River, near Nellie, Cal., for January, 1916.*

[Made by W. J. Isbell.]

| Date. | Gage height. | Discharge. | Date. | Gage height. | Discharge. |
|---|---|---|---|---|---|
| | *Feet.* | *Sec.-ft.* | | *Feet.* | *Sec.-ft.* |
| Jan. 8 | 1.30 | 22 | Jan. 22 | 3.02 | 571 |
| 15 | 2.30 | 194 | | | |

*Mean daily discharge, in second-feet, of San Luis Rey River near Nellie, Cal., for January, 1916.*

| Date. | Discharge. | Date. | Discharge. | Date. | Discharge. | Date. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 25 | Jan. 5 | 38 | Jan. 9 | 140 | Jan. 13 | 60 |
| 2 | 43 | 6 | 48 | 10 | 55 | 14 | 63 |
| 3 | 41 | 7 | 29 | 11 | 58 | 15 | 194 |
| 4 | 26 | 8 | 22 | 12 | 59 | | |

Total run-off for month {acre-feet ........ 165,000
Total run-off for month {depth in inches on drainage area ........ 12.91

### SAN LUIS REY RIVER NEAR PALA, CAL.

**Location.**—Above ford on road to Sickler's mill, in the NW. ¼ sec. 31, T. 9 S., R. 1 W., about 4 miles southeast of Pala, San Diego County.

**Drainage area.**—322 square miles (measured on topographic and military-survey maps).

**Elevation.**—About 575 feet above sea level.

**Records available.**—October 9, 1903 to June 30, 1911, and November 14, 1912, to January, 1916.

**Gage.**—Friez water-stage recorder on left bank 600 feet above ford. Previous to September 19, 1912, records were obtained from staff gage about 50 feet above ford. November 13, 1906, original gage datum was lowered 4.66 feet. Present gage is at an independent datum. Water-stage recorder was removed by high water in January; no record after January 16, 1916.

**Discharge measurements.**—Made from cable 550 feet below water-stage recorder or by wading.

**Channel and control.**—Composed of sand, gravel, and boulders; shifting. An artificial control, consisting of short concrete cut-off walls between the boulders, was rebuilt across the channel just below gage on September 28, 1914, and was destroyed by flood of January, 1916. Stage of zero flow for new control. about 5.7 feet.

**Extremes of discharge.**—1905–1915: Maximum stage recorded, 12.0 feet (original datum) at noon and at 2 p. m. March 24, 1906 (discharge, 22,000 second-feet); minimum stage, 5.28 feet August 6 and 7, 1907 (discharge, 0.6 second-foot).

Maximum discharge in January, 1916.—Maximum stage reached during flood was 18.1 feet, as determined by leveling from high-water mark. Maximum discharge was approximately 75,000 second-feet (see San Luis Rey at Pala).

Accuracy.—Results January 1 to 16 considered good; no gage-height record after January 16, as equipment was destroyed. Discharge January 17 to 31 estimated from flood studies of Mesa Grande and Oceanside records, and mean rainfall computed for drainage area.

*Mean daily discharge, in second-feet, of San Luis Rey River near Pala, Cal., for January, 1916.*

| Date. | Discharge. | Date. | Discharge. | Date. | Discharge. | Date. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 18 | Jan. 5 | 18 | Jan. 9 | 34 | Jan. 13 | 99 |
| 2 | 18 | 6 | 26 | 10 | 119 | 14 | 92 |
| 3 | 27 | 7 | 25 | 11 | 289 | 15 | 311 |
| 4 | 18 | 8 | 18 | 12 | 161 | 16 | 1,660 |

Total run-off for month {acre-feet ........ 201,000
depth in inches on drainage area ........ 11.76

### SAN LUIS REY RIVER AT PALA, CAL.

Location.—300 feet above intake of South Side Pala Indian ditch, below Agua Tibia Creek, 1½ miles below Geological Survey gaging station, and about 1½ miles southeast of Pala, San Diego County.

Drainage area.—322 square miles (at Geological Survey gaging station, 1½ miles upstream, measured on topographic and military-survey maps).

Elevation.—About 500 feet above sea level.

Flood discharge for January, 1916.—About 30 days after the flood, Mr. C. H. Southworth, United States Indian Irrigation Service, measured cross-section and slope at this point and computed the maximum discharge for January 27, as follows: Area, 2,690 square feet; wet perimeter, 300 feet; hydraulic radius, 8.9; slope, 0.012; assumed value of $n$ inKutter's formula, 0.025; mean velocity, 28.0 feet per second; discharge, 75,300 second-feet.

### SAN LUIS REY RIVER AT BONSALL, CAL.

Location.—In the SW. ¼ sec. 20, T. 10 S., R. 3 W., at concrete highway bridge at Bonsall, San Diego County, just above Moosa Canyon, about 14 miles below gaging station near Pala, and 14 miles above mouth of river.

Drainage area.—465 square miles (measured on topographic and military survey maps).

Elevation.—About 150 feet above sea level.

Records available.—April 16, 1912, to January, 1916.

Gage.—Staff in three sections on left bank at bridge; read twice daily. Previous staff was on left bank, 150 feet below present gage. Original datum not maintained.

Discharge measurements.—Made from bridge at gage or by wading.

Channel and control.—Composed of sand; shifting.

Extremes of discharge.—1912–1915: Maximum stage recorded, 7.0 feet February 11, 1915 (discharge 9,000 second-feet); channel dry for several months each year.

Maximum discharge in January, 1916.—Gage and highway bridge destroyed by high water; no record after January 15. Maximum discharge not estimated owing to instability of channel.

Accuracy.—Results January 1 to 15 considered fair. Discharge for remainder of month estimated from flood studies of Mesa Grande and Oceanside records and mean rainfall computed for drainage area.

*Mean daily discharge, in second-feet, of San Luis Rey River at Bonsall, Cal., for January, 1916.*

| Date. | Discharge. | Date. | Discharge. | Date. | Discharge. | Date. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 57 | Jan. 5 | 42 | Jan. 9 | 57 | Jan. 13 | 86 |
| 2 | 57 | 6 | 42 | 10 | 95 | 14 | 86 |
| 3 | 57 | 7 | 57 | 11 | 320 | 15 | 268 |
| 4 | 57 | 8 | 57 | 12 | 162 | | |

| Total run-off for month | |
|---|---|
| acre-feet | 257,000 |
| depth in inches on drainage area | 10.36 |

## SAN LUIS REY RIVER AT OCEANSIDE, CAL.

**Location.**—In the SE. ¼ NE. ¼ sec. 22, T. 11 S., R. 5 W., at highway bridge about half a mile above mouth, at Oceanside, San Diego County.

**Drainage area.**—565 square miles (measured on topographic and military survey maps); for gaging station opposite Oceanside pumping plant, 1½ miles upstream, 563 square miles.

**Elevation.**—Sea level.

**Records available.**—April 17, 1912, to September 30; 1915, for station opposite Oceanside pumping plant.

**Discharge measurements.**—Made from concrete highway bridge until its failure at 9.30 p. m., January 27, 1916. Later measurements were made from a boat at approximately the same location (Pl. VIII, *A*, p. 32).

**Channel and control.**—Composed of sand; shifting. The discharge measurement made at 6 p. m., January 27, 1916, indicated that the scour in the main channel amounted to about 10 feet as compared with the cross section measured May, 25 1916.

**Extremes of discharge.**—1912–1915: Maximum stage recorded at station opposite Oceanside pumping plant, 4.9 feet February 11, 1915 (approximate discharge, 7,000 second-feet); channel dry for several months during each year.

**Maximum discharge in January, 1916.**—The crest discharge of the flood on January 17, 1916, was estimated from the Mesa Grande record, using the ratio that obtained for the flood of January 27, at 40,000 second-feet. The crest discharge, which occurred at 9.30 p. m. January 27, was estimated as follows: From a study of the cross section measured May 25 and the measurement at 6 p. m. January 27, it is evident that the maximum stage at 9.30 p. m. was at least 3.0 feet higher than at the time of the measurement. At the pumping plant, 1½ miles upstream, where the channel is much wider, a rise of more than 2 feet was reported. Low tide occurred at 7.15 p. m. January 27; hence the maximum stage was not affected by the tide. Without making any allowance for additional scour in the channel, the area at maximum stage would be 1,860 square feet greater than at 6 p. m., or a total area of 6,370 square feet. The mean velocity has been estimated as 15 feet per second. For the measurement at 6 p. m. it was 12.3 feet per second. The estimated maximum discharge is 95,600 second-feet, or 169 second-feet per square mile.

**Accuracy.**—Mean daily discharge January 16 to 31, 1916, computed from a hydrograph based on discharge measurements and compared with the records on San Luis Rey River near Mesa Grande. Results considered fair.

*Discharge measurements of San Luis Rey River at Oceanside, Cal., for January, 1916.*

| Date. | Made by— | Gage height. | Discharge. | Remarks. | |
|---|---|---|---|---|---|
| | | | | Time of measurement. | Method. |
| 1916. | | *Feet.* | *Sec.-ft.* | | |
| Jan. 16 | McFadden and Ireland | 2.45 | 216 | 9 a. m. | |
| 17 | Strout and Ireland | 6.0 | 27,100 | 3 p. m. | Meter and floats. |
| 18 | .....do | 4.0 | 16,200 | 9 a. m. | Floats. |
| 18 | .....do | 4.0 | 20,800 | 3 p. m. | Do. |
| 19 | .....do | 3.0 | 9,990 | 9 a. m. | Do. |
| 19 | .....do | 2.5 | 9,080 | 4 p. m. | Do. |
| 20 | .....do | 2.0 | 3,690 | 10 a. m. | Do. |
| 21 | .....do | 1.8 | 2,000 | 9 a. m. | Meter. |
| 22 | C. B. Ireland | 1.4 | 1,650 | 11 a. m. | Do. |
| 22 | .....do | 1.4 | 1,490 | 4 p. m. | Do. |
| 23 | .....do | 1.3 | 1,460 | 9 a. m. | Do. |
| 23 | .....do | 1.3 | 1,240 | 4 p. m. | Do. |
| 24 | .....do | 1.3 | 1,150 | 9 a. m. | Do. |
| 24 | .....do | 1.3 | 1,090 | 4 p. m. | Do. |
| 25 | .....do | 1.4 | 1,310 | 9 a. m. | Do. |
| 25 | .....do | 1.5 | 1,580 | 4 p. m. | Do. |
| 26 | .....do | 1.6 | 1,800 | 9 a. m. | Do. |
| 27 | Strout and Ireland | .......... | 9,640 | 10 a. m. | Floats. |
| 27 | .....do | .......... | 55,400 | 6 p. m. | Do. |
| 28 | Strout and Bowen | .......... | 21,900 | 9 a. m. | Do. |
| 30 | G. S. Strout | .......... | 2,190 | 4 p. m. | Do. |
| 31 | .....do | .......... | 1,280 | 4 p. m. | Do. |

Note.—Mean velocities taken as 80 per cent of surface velocities obtained from floats.

*Discharge, in second-feet, of San Luis Rey River at Oceanside, Cal., for January, 1916.*

| Date. | Maximum. | Minimum. | Mean. | Date. | Maximum. | Minimum. | Mean. |
|---|---|---|---|---|---|---|---|
| Jan. 16 | 6,500 | 216 | 2,180 | Jan. 24 | 1,200 | 1,080 | 1,110 |
| 17 | 40,000 | 10,000 | 20,800 | 25 | 1,600 | 1,100 | 1,400 |
| 18 | 21,500 | 13,500 | 18,100 | 26 | 3,800 | 1,600 | 2,230 |
| 19 | 13,500 | 5,700 | 9,640 | 27 | 95,600 | 3,800 | 33,800 |
| 20 | 5,700 | 2,400 | 3,730 | 28 | 85,000 | 7,700 | 28,200 |
| 21 | 2,400 | 1,700 | 1,980 | 29 | 7,700 | 3,700 | 5,330 |
| 22 | 1,700 | 1,480 | 1,590 | 30 | 3,700 | 1,800 | 2,650 |
| 23 | 1,480 | 1,200 | 1,350 | 31 | 1,800 | 1,170 | 1,430 |

| Total run-off for period | | |
|---|---|---|
| | acre-feet | 269,000 |
| | depth in inches on drainage area | 8.92 |

## MOOSA CANYON CREEK NEAR BONSALL, CAL.

Location.—Near the northwest corner of sec. 1, T. 11 S., R. 3 W., at Moose dam, half a mile below mouth of South Fork, and 4½ miles southeast of Bonsall, San Diego County.

Drainage area.—31 square miles (measured on topographic map by John F. Covert).

Elevation.—About 400 feet above sea level.

Maximum discharge in January, 1916.—John F. Covert, chief engineer Sweetwater Water Co., estimated the discharge over the dam to be 8,346 second-feet. The maximum stage 100 feet upstream from the dam, determined December 15, 1916, from flood marks was 9.1 feet above crest of dam. The concrete dam is 81 feet long on top and the width of the canyon at a point 9.1 feet above the crest is 105 feet.

## SANTA ANA RIVER BASIN.

### GENERAL FEATURES.

Of the three principal streams that traverse the valley of southern California—Santa Ana, San Gabriel, and Los Angeles rivers—the Santa Ana is the largest. Its drainage basin, lying south of the San Bernardino Mountains and the Sierra Madre and taking waters from their southern slopes, is the most easterly and comprises by far the largest area, including the northern part of Orange County, the northwestern part of Riverside County, and the southwestern part of San Bernardino County. Of the total drainage area, covering between 1,800 and 1,900 square miles, about two-thirds is in the valley, but only a few hundred square miles yields much run-off.

The Santa Ana rises in the heart of the San Bernardino Mountains, about 30 miles east of Highland, and flows westward for about 25 miles to the mouth of its upper canyon; thence southwestward across San Bernardino Valley, through the lower canyon in the Santa Ana Mountains, and across the coastal plain to the Pacific Ocean at Newport Beach. Although the course of the stream measures about 100 miles, there is continuous surface flow from mountain to sea only during winter floods.

Many small streams from the southern slope of the San Bernardino Mountains and a few from the Sierra Madre west of the Cajon Pass flow toward the Santa Ana, but some of these discharge water to the main stream only in the flood seasons, the ordinary flow either being diverted or sinking into the sand and gravel of San Bernardino Valley. The principal tributaries are Bear, Alder, Mill, Lytle, and Chino creeks.

Altitudes in the Santa Ana drainage area range from a few feet above sea level on the coastal plain to 2,000 or 3,000 feet on the Santa Ana Mountains, 500 to 1,200 feet in the San Bernardino basin, and 2,000 to 11,000 feet on the southern slope of the San Bernardino Mountains. The more elevated regions are rough and rugged, and the mountain sides are incised by many canyons which are the result of active stream erosion. The rocks are granitic. The mesa and valley lands at the base of the mountains are composed of granitic gravel and sand of great depth. The higher mountain slopes support considerable timber; most of the lower slopes are covered with brush and grass.

The mean annual precipitation varies considerably in different parts of the Santa Ana basin. On the coastal plain west of the Santa Ana Range it averages 10 inches or more; eastward, in the San Bernardino Valley, it amounts to from 10 to 16 inches. On the mountain slopes it ranges from 20 inches at the base to 40 inches or more near the crest, and in Bear Valley north of the highest peaks, such as San Bernardino and San Gorgonio, it may be even 50 inches. Considerable snow falls in the region of these high peaks in winter and remains well into the summer, especially on the northern slopes, from which the headwaters of the Santa Ana come.

### SANTA ANA RIVER NEAR MENTONE, CAL.

**Location.**—In the SW. ¼ sec. 4, T. 1 S., R. 2 W., just above mouth of canyon, one-fourth mile above Pacific Light & Power Corporation's plant, one-half mile above mouth of Deep Creek, and 3½ miles northeast of Mentone, San Bernardino County.

**Drainage area.**—189 square miles (measured on topographic maps).

**Elevation.**—About 1,900 feet above sea level.

**Records available.**—July 1, 1896, to January, 1916.

**Gage.**—Vertical staff fastened to rock ledge on left bank one-fourth mile above power house; read daily. Destroyed by high water during night of January 17–18; no record obtained during rest of month.

**Discharge measurements.**—Car and cable at Warm Springs Canyon destroyed by flood. On account of the damage to the highways and bridges it was impossible to reach this station for several days after the flood had passed.

**Channel and control.**—Composed of gravel and boulders; very rough; shifts during high water.

**Extremes of discharge.**—1896–1915: Crest gage height January 1, 1910, not known, as gage was destroyed (mean discharge for day estimated as 8,500 second-feet); minimum stage, 2.3 feet during parts of every month from October, 1913, to January, 1915 (discharge, 0.6 second-foot).

**Maximum discharge in January, 1916.**—As the gage was destroyed during the night of January 17–18, there is no record of stage for the month after 8 a. m. January 17. Slope cross section measured at the gaging station March 8, 1916 (Pl. XVI, *A*). The cross section was measured just below temporary highway bridge, 357 feet below gage. The channel, which is composed of large and small boulders, sand, and gravel, is clean and very rough. The slope of the water surface at maximum stage was determined for a distance of 1,620 feet, where the channel was generally straight. The maximum discharge has been computed as follows: Width, 510 feet; wet perimeter, 526 feet; area, 2,290 square feet; hydraulic radius, 4.4; slope of water surface (flood stage), 0.024 (for 1,620 feet). If the value of $n$ in Kutter's formula is assumed as 0.05, the discharge is 29,100 second-feet, or 154 second-feet per square mile of drainage area.

For purpose of comparison it is interesting to note that the intake of the Mentone power plant, operator's house, and other structures removed by this flood had been in place since the plant was constructed in 1902. Also that a large number of trees, 2 feet in diameter, were brought down by the high water. During the flood the river at the mouth of the canyon, would swing from one side of the canyon to the other and back again, within an hour, the action being due to jams formed by great numbers of large boulders moving downstream.

**Diversions.**—The intake of the Pacific Light & Power Corporation's canal is at Southern California Edison Co. plant No. 2, 2½ miles above the gage. The intake of this canal was washed out at 8.40 a. m. January 17, 1916. No water was diverted through it during the rest of the month.

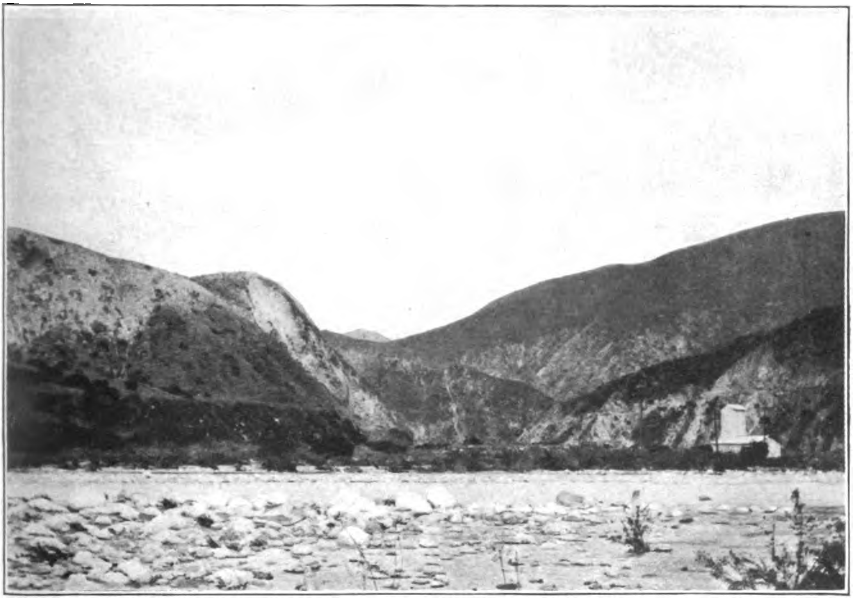
**Regulation.**—Water is stored on Bear Creek at Bear Valley reservoir.

### SANTA ANA RIVER AT SAN BERNARDINO, CAL.

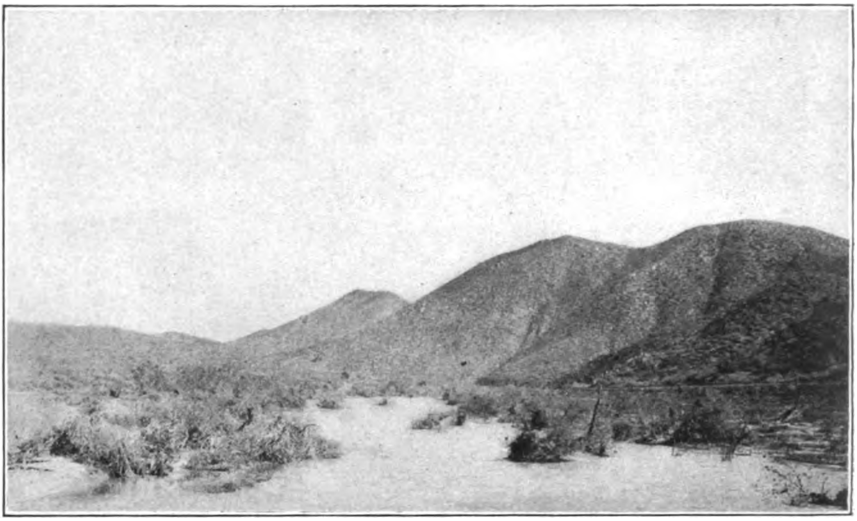
**Location.**—At Salt Lake Street Bridge (E Street), San Bernardino, San Bernardino County.

**Maximum discharge in January, 1916.**—Mr. H. B. Andrews, Riverside Water Co., who measured cross section and slope, from high-water marks which he observed

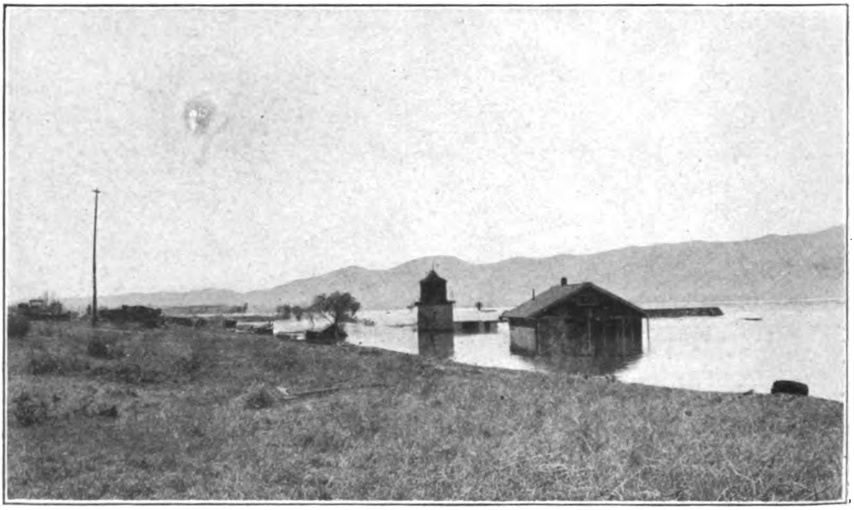
*A.* GAGING STATION ON SANTA ANA RIVER NEAR MENTONE, AFTER FLOOD OF JANUARY, 1916.



*B.* VIEW ACROSS CHANNEL OF SAN GABRIEL RIVER AT MOUTH OF CANYON, NEAR AZUSA, AFTER FLOOD OF JANUARY, 1916.



*A.* VIEW UPSTREAM ON SAN JACINTO RIVER NEAR ELSINORE, AFTER FLOOD OF JANUARY, 1916.



*B.* VIEW EASTWARD ALONG NORTH SHORE OF ELSINORE LAKE, MARCH 10, 1916.

during the storm of January 17, has estimated the discharge as follows: Area, 2,020 square feet; wet perimeter, 251 feet; slope, 0.006; discharge, 40,000 second-feet. The high-water marks on January 27 were practically the same as for January 17.

The following discharge measurements at Salt Lake Street Bridge, furnished by Riverside Water Co., include San Timoteo Creek and Redlands Wash, but do not show diversions by Gage canal at Sterling Street.

*Discharge measurements of Santa Ana River at San Bernardino, Cal., during January, 1916.*

[Made by H. B. Andrews.]

| Date. | Discharge. | Time of measurement. | Date. | Discharge. | Time of measurement. |
|---|---|---|---|---|---|
| | *Sec.-ft.* | | | *Sec.-ft.* | |
| Jan. 6 | 127 | 3.50 p. m. | Jan. 22 | 730 | 2.15 p. m. |
| 20 | 1,106 | 4.15 p. m. | 28 | 3,725 | 12.35 p. m. |

## LYTLE CREEK AT SAN BERNARDINO, CAL.

The following table was compiled from a blue-print hydrograph furnished by J. A. Sourwine, county engineer. This hydrograph was determined from measurements of East and West channels of Lytle Creek. The West channel was measured at the new Fourth Street Bridge until it went out at 8.05 a. m. January 18. Later measurements were made at the Atchison, Topeka & Santa Fe Railway bridge, at North Colton. The East channel was measured at the old Fourth Street Bridge until about 9 a. m. January 18, and later at Mount Vernon Avenue Bridge. The discharge record given in the table was taken from the hydrograph at points where there was a change in curvature. A planimeter was used to determine mean daily discharge.

*Discharge, in second-feet, of Lytle Creek at San Bernardino, Cal., for January, 1916.*

| Date. | Time. | Discharge. | Mean daily discharge. | | |
|---|---|---|---|---|---|
| | | | East channel. | West channel. | Total. |
| Jan. 16 | 10.00 p. m. | Dry. | | | |
| 17 | 3.00 a. m. | 650 | 920 | 4,320 | 5,240 |
| | 7.30 a. m. | 6,200 | | | |
| | 10.00 a. m. | 13,400 | | | |
| | 12.45 p. m. | 6,200 | | | |
| | 3.30 p. m. | 8,500 | | | |
| | 11.00 p. m. | 2,650 | | | |
| Jan. 18 | 5.00 a. m. | 8,000 | | | 6,640 |
| | 9.40 a. m. | 16,000 | | | |
| | 1.00 p. m. | 8,000 | | | |
| | 4.30 p. m. | 2,800 | | | |
| Jan. 19 | 10.00 a. m. | 550 | | | |
| | 5.00 p. m. | 350 | | | |

### SAN JACINTO RIVER NEAR SAN JACINTO, CAL.

**Location.**—In sec. 20, T. 5 S., R. 2 E., at Oak Cliff, 1 mile above mouth of North Fork of San Jacinto River and 10 miles southeast of San Jacinto, Riverside County.

**Drainage area.**—108 square miles (measured on topographic map).

**Elevation.**—About 2,200 feet above sea level.

**Maximum discharge in January, 1916.**—Mr. W. S. Post, consulting engineer, measured cross section and slope at this point and estimated the crest discharge as follows: Area, 2,058 square feet; wet perimeter, 392 feet; hydraulic radius, 5.2; slope, 0.029; discharge, 30,000 second-feet or 278 second-feet per square of drainage area.

### SAN JACINTO RIVER NEAR ELSINORE, CAL.

**Location.**—Near center of sec. 9, T. 6 S., R. 4 W., at A. T. & S. F. Ry. bridge at Elsinore Junction, about 1½ miles above junction with Elsinore Lake (low-water stage), and 1½ miles southeast of Elsinore, Riverside County.

**Drainage area.**—718 square miles (measured on topographic maps).

**Elevation.**—About 1,250 feet above sea level.

**Records available.**—January 1 to 31, 1916.

**Gage.**—Vertical staff fastened to trestle bent of railway bridge near left bank; read daily.

**Discharge measurements.**—Made from railway bridge or by wading.

**Channel and control.**—Composed of gravel and small boulders; fairly permanent.

**Maximum discharge in January, 1916.**—Measurements of cross section and slope were made March 9 in the canyon about three-fourths mile above gaging station at railway bridge. The channel at this point is composed of sand and gravel with a few small boulders and is straight. Along the banks of the low-water channel there are small bushes and a few trees. There is but one channel at all stages and the high-water banks are clean (Pl. XVII, *A*). The slope of the water surface at maximum stage was determined for a distance of 1,150 feet. The crest discharge has been computed as follows: Width, 290 feet; wet perimeter, 295 feet; area, 1,730 square feet; hydraulic radius, 5.9; slope of water surface (flood stage), 0.0033. If the value of *n* in Kutter's formula is assumed as 0.035, the discharge is 14,000 second-feet, or 195 second-feet per square mile of drainage area (drainage area at this point, 717 square miles measured on topographic maps). This discharge occurred January 28 at 11 a. m., gage height 19.0 feet.

**Accuracy.**—Gage height record affected by backwater from Elsinore Lake beginning January 30. Rating curve defined by two medium-stage measurements and maximum of flood discharge computed from cross-section and slope. Gage read once a day to hundredths feet. Results fair.

*Daily discharge, in second-feet, of San Jacinto River near Elsinore, Cal., for January, 1916.*

| Date. | Discharge. | Date. | Discharge. | Date. | Discharge. | Date. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 2 | Jan. 9 | 3 | Jan. 17 | 730 | Jan. 25 | 730 |
| 2 | 2 | 10 | 3 | 18 | 830 | 26 | 580 |
| 3 | 2 | 11 | 3 | 19 | 1,750 | 27 | 1,010 |
| 4 | 2 | 12 | 2 | 20 | 6,800 | 28 | 14,000 |
| 5 | 2 | 13 | 2 | 21 | 1,750 | 29 | 6,800 |
| 6 | 2 | 14 | 2 | 22 | 1,010 | 30 | 1,750 |
| 7 | 2 | 15 | 2 | 23 | 580 | 31 | 1,350 |
| 8 | 2 | 16 | 2 | 24 | 680 | | |

| Total run-off for month | | |
|---|---|---|
| | acre-feet | 79,900 |
| | depth in inches on drainage area | 2.09 |

*Discharge measurements of San Jacinto River near Elsinore, Cal., during January, 1916.*

[Made by F. C. Ebert.]

| Date. | Gage height. | Discharge. |
|---|---|---|
| | *Feet.* | *Sec.-ft.* |
| Jan. 25 | 10.40 | 680 |
| 26 | 10.32 | 651 |

### HISTORY OF ELSINORE LAKE.[1]

Apparently the earliest specific reference to the amount of water in Elsinore Lake is contained in the notes of a traveler through southern California about 1810, who mentions "Laguna Grande," the original Mexican name for the lake, as being little more than a swamp about a mile long. For the period between that time and 1862 data as to its rise and fall are not available, but in 1862 it was very high and probably overflowed. During the succeeding dry period, especially during the years 1866 and 1867, when practically no rain fell on the drainage area tributary to the lake, it receded very rapidly but was full again in 1872 and overflowed down its outlet through Temescal Canyon. After this it again evaporated to a level probably as low as it has ever been since, but the great rains of the winter of 1883–84 filled it to overflowing in three weeks.

Americans had settled around it by this time and their descriptions of conditions say that large willow trees surrounding the low-water shore line were of such size that they must have been thirty or more years old. The rainfall in the next ten years was excessive, and the lake stayed high and overflowed naturally during three or four years of the decade. It was purchased by the Temescal Water Co. for the irrigation of lands at Corona, Cal., and its outlet channel was deepened, permitting gravity flow to Corona for a year or more after the lake level had sunk below the elevation of its outlet. As the surface still receded a pumping plant was installed and the water was raised a maximum of about 10 feet and then flowed down the natural channel of Temescal Canyon. Pumping was continued a couple of seasons, but the concentration of salts in the lake, due to the evaporation and low rainfall, soon made the water unfit for irrigation.

After 1893 the water level sank almost continuously for nearly ten years, with, of course, a slight rise every winter. The heavier precipitation, beginning in 1903, gradually filled the lake to about half the depth between its minimum level since 1883 and its high level or overflow point. The flood of January, 1916, rapidly raised the level, to overflowing, although the run-off from its drainage area into the lake appears to have been considerably less than that of the wet years of 1883–84 and 1888–89. (See Pl. XVII, *B*.)

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[1] Prepared by Francis R. Schanck, assistant inspector of irrigation, United States Indian Office, Los Angeles, Cal.

The fact that large trees were growing 20 feet or more below the high-water level when the lake filled in 1883–84 indicates that the high water of the sixties and seventies must have been of very short duration. The stumps of the trees were still visible in 1888 and 1889 many hundred feet from shore, but by the time the lake receded in the middle nineties these had disappeared.

### ELSINORE LAKE AT ELSINORE, CAL.

**Location.**—In La Laguna grant at outlet of lake at Elsinore, Riverside County.

**Gage.**—Vertical staff installed December 1, 1915; datum 1,237.20 feet above sea level. The water surface rose above this gage and a new staff was installed January 25, 1916; datum 1,237.53 feet. This gage was flooded and the observer installed a temporary staff on January 30, 1916, at approximately the same datum, but before it could be referred to previous datum it also was flooded.

*Daily elevation, in feet above sea level, of Elsinore Lake at Elsinore, Cal., for January, 1916.*

| Date. | Elevation. | Date. | Elevation. | Date. | Elevation. | Date. | Elevation. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 1,245.4 | 9 | 1,245.4 | 17 | 1,246.7 | 24 | 1,252.9 |
| 2 | 1,245.3 | 10 | 1,245.4 | 18 | 1,247.2 | 25 | 1,253.2 |
| 3 | 1,245.3 | 11 | 1,245.4 | 19 | 1,248.7 | 26 | 1,254.0 |
| 4 | 1,245.3 | 12 | 1,245.4 | 20 | 1,250.2 | 27 | 1,254.5 |
| 5 | 1,245.3 | 13 | 1,245.4 | 21 | 1,251.2 | 28 | 1,255.5 |
| 6 | 1,245.3 | 14 | 1,245.4 | 22 | 1,252.2 | 29 | 1,257.5 |
| 7 | 1,245.3 | 15 | 1,245.4 | 23 | 1,252.7 | 30 | 1,258.5 |
| 8 | 1,245.3 | 16 | 1,245.4 | | | | |

### SOUTH FORK OF SAN JACINTO RIVER AT HEMET RESERVOIR, NEAR SAN JACINTO, CAL.

**Location.**—The dam is in sec. 7, T. 6 S., R. 3 E., below Hemet Valley, about 6 miles above mouth of South Fork of San Jacinto River, and 17 miles southeast of San Jacinto, Riverside County.

**Drainage area.**—65.8 square miles (at dam; measured on topographic map).

**Elevation.**—About 4,350 feet above sea level.

**Discharge.**—The following table, computed by Mr. W. S. Post, consulting engineer, shows the run-off into Hemet reservoir.

*Gage height, in feet, and discharge, in second-feet, of South Fork of San Jacinto River at Hemet reservoir, near San Jacinto, Cal., for January, 1916.*

| Date. | Time. | Reservoir gage height. | Instantaneous discharge into reservoir. | Mean daily discharge. | Date. | Time. | Reservoir gage height. | Instantaneous discharge into reservoir. | Mean daily discharge. |
|---|---|---|---|---|---|---|---|---|---|
| Jan. 14 | 8 a. m. | 116.65 | 22 | 54 | 22 | 8 a. m. | 122.5 | 146 | 146 |
| 15 | 8 a. m. | 116.88 | 39 | 42 | 23 | 8 a. m. | 122.5 | 146 | 146 |
| 16 | 8 a. m. | 117.17 | 137 | 164 | 24 | 8 a. m. | 122.5 | 162 | 176 |
| 17 | 2 p. m. | 119.17 | 2,810 | 1,450 | 25 | 8 a. m. | 122.67 | 228 | 190 |
| | 6 p. m. | 124.5 | 3,200 | .......... | 26 | 8 a. m. | 122.67 | 212 | 212 |
| | 12 p. m. | 125.83 | 1,440 | .......... | 27 | 8 a. m. | *a* 122.67 | 1,710 | 5,070 |
| 18 | 8 a. m. | 124.5 | 822 | 754 | | 4 p. m. | 128.0 | 9,550 | .......... |
| | 8 p. m. | 123.67 | 930 | .......... | 28 | 8 a. m. | 125.0 | 2,460 | 2,880 |
| | 12 p. m. | *a* 123.5 | 748 | .......... | 29 | 8 a. m. | 123.92 | 1,300 | 1,390 |
| 19 | 12 p. m. | *a* 122.67 | 88 | 412 | 30 | 8 a. m. | 123.83 | 1,180 | 980 |
| 20 | 8 a. m. | 122.5 | 100 | 126 | 31 | 8 a. m. | 122.92 | 260 | 349 |
| 21 | 8 a. m. | 122.5 | 146 | 146 | | | | | |

*a* Interpolated.

| Total run-off for period | | |
|---|---|---|
| | acre-feet | 29,100 |
| | depth in inches on drainage area | 8.30 |

**Note.**—Table summarizes the detailed computations, based on notes furnished by the water company and covering stage of reservoir, spillway discharge, gate leakage, and other conditions.

## SAN GABRIEL RIVER BASIN.

### GENERAL FEATURES.

San Gabriel River is one of the three large streams traversing the valley of southern California. Its drainage basin lies wholly in Los Angeles County west of the Santa Ana basin and east of the Los Angeles basin and stretches from the crest of the Sierra Madre to the Pacific, a distance of about 50 miles. Its total drainage area is approximately 700 square miles, about one-third of which consists of mountain slopes, which contribute practically all of the run-off except in heavy storms. The remaining two-thirds is embraced in the San Gabriel Valley at the base of the mountains and in the coastal plain southeast of the city of Los Angeles.

The mountainous part of the basin is somewhat rectangular. Its length east and west is about 25 miles, and its width about 10 miles. It lies on the southern slope of the Sierra Madre opposite the basins of Big and Little Rock creeks at the north and on the southern slope of the San Gabriel Range, through which the river breaks near Azusa and enters the San Gabriel Valley.

The main stream is formed by the junction of two principal forks, one from the north and east and the other from the west. Each of the branches receives many tributaries from the crests of the surrounding ranges. The headwaters come from the western slope of San Antonio Peak (Old Baldy), altitude 10,080 feet, and from the southern slope of other high peaks at the north, such as North Baldy and Islip mountains. The west fork drains the northern slope of Mount Wilson, the eastern and northern slopes of San Gabriel Peak, and a portion of the southern slopes of the main range to the north. It joins the main stream about 8 miles above the mouth of the canyon. The general course of the stream is southwestward. After leaving the mountains it traverses San Gabriel Valley in a wide wash of sand, gravel, and boulders, then breaks through the range of foothills separating San Gabriel Valley from the coastal plain at a point called The Narrows, about 5 miles northwest of Whittier, and enters the coastal plain, across which it flows to its mouth in Alamitos Bay, a few miles east of Long Beach. The total length of the stream is about 65 or 70 miles.

The principal tributaries of San Gabriel River are Fish Fork and Cattle Creek from the east, and Iron and West forks from the west.

Altitudes in San Gabriel basin range from 20 to 200 feet on the Coastal Plain from 200 to 900 feet in San Gabriel Valley, and from 1,000 to 10,000 feet in the mountains. The range of foothills near Whittier has an altitude of about 1,250 feet. The topography is rough and rugged in the mountains, especially in the upper part, where deep and narrow canyons exist. The geologic formation is granitic, with a light soil covering. The San Gabriel Valley is more or less rolling and is composed of granitic wash from the mountains.

The basin is rather poorly forested, having a sparse timber growth on the higher slopes and brush with some scattered timber on the middle and lower elevations.

The mean annual precipitation in this basin ranges from 15 to 20 inches in the valley area, and from 20 to 40 inches in the mountains. It occurs almost entirely as rain except on the higher peaks, where snow falls during the winter. On the northern slopes snow remains for several weeks.

### SAN GABRIEL RIVER NEAR AZUSA, CAL.

**Location.**—In the NW. ¼ sec. 23, T. 1 N., R. 10 W., near road crossing at mouth of canyon, about half a mile above the Pacific Light & Power Corporation's power house and 2 miles north of Azusa, Los Angeles County.

**Drainage area.**—222 square miles.

**Elevation.**—About 750 feet above sea level.

**Records available.**—1894 to January 31, 1916.

**Gage.**—Staff were fastened to rock point on left bank about 200 feet above ford, read daily; oftener during floods. Gage used January 2 to 8 and 12 to 16, 1916, is on left bank about 600 feet below ford at an independent datum.

**Discharge measurements.**—Made from cable 1,000 feet above ford or by wading near gage. The float measurements on January 17 and 18, 1916, were made just below gage. The cross-section for these measurements, secured March 8, 1916, was taken 145 feet below regular gage (Pl. XVI, *B*, p. 68).

**Channel and control.**—Composed of gravel and boulders; shifts during high water.

**Extremes of discharge.**—1894–1915: Maximum stage recorded, 11.7 feet February 20, 1914 (discharge, 18,100 second-feet); minimum stage, dry for several months during each year.

**Maximum discharge in January, 1916.**—The crest of the flood occurred at 7 a. m., January 18; gage height, 12.0 feet (discharge, 40,000 second-feet).

**Diversions.**—The power canal of the Pacific Light & Power Corporation heads about 5 miles above the station. No water in this canal from afternoon of January 17 to the morning of January 19, as the intake was closed by drift.

**Regulation.**—None.

**Accuracy.**—Results considered good for January, 1916. Rating curves for extreme high water are defined by the float measurements made January 17 and 18. A coefficient of 0.80 was used to reduce float velocities to mean velocities. There was doubtless a fill in the channel after the crest of the flood on January 18 and hence the areas for the float measurements are probably low.

*Discharge measurements of San Gabriel River near Azusa, Cal., for January, 1916.*

[Made by F. C. Ebert.]

| Date. | Gage height. | Discharge. | Date. | Gage height. | Discharge. | Date. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|---|
| | *Feet.* | *Sec.-ft.* | | *Feet.* | *Sec.-ft.* | | *Feet.* | *Sec.-ft.* |
| Jan. 3 | [a]1.82 | 63 | Jan. 15 | [a]2.08 | 117 | Jan. 19 | 7.10 | 3,750 |
| 4 | [a]1.62 | 39 | 17 | 10.30 | [b]18,400 | 20 | 6.62 | 2,380 |
| 12 | [a]2.03 | 107 | 18 | 11.50 | [b]32,400 | 21 | 6.34 | 1,570 |
| 13 | [a]1.88 | 76 | 19 | 7.38 | 4,300 | 24 | 5.80 | 848 |

[a] Gage below ford read.

[b] Float measurements.

*Combined daily discharge, in second-feet, of San Gabriel River and Pacific Light & Power Corporation's canal near Azusa, Cal., for January, 1916.*

| Date. | Discharge. | Date. | Discharge. | Date. | Discharge. | Date. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 63 | 9 | 480 | Jan. 17 | 17,100 | Jan. 25 | 840 |
| 2 | 93 | 10 | 820 | 18 | 22,300 | 26 | 700 |
| 3 | 159 | 11 | 480 | 19 | 3,980 | 27 | 7,940 |
| 4 | 117 | 12 | 190 | 20 | 2,450 | 28 | 4,290 |
| 5 | 179 | 13 | 159 | 21 | 1,650 | 29 | 2,240 |
| 6 | 142 | 14 | 135 | 22 | 1,410 | 30 | 2,080 |
| 7 | 117 | 15 | 215 | 23 | 1,250 | 31 | 1,790 |
| 8 | 102 | 16 | 179 | 24 | 928 | | |

Total run-off for month {acre-feet ........ 148,000
Total run-off for month {depth in inches on drainage area ........ 12.57

NOTE.—Water began flowing in river at gaging station on Jan. 2; discharge Jan. 17 and 18 computed from several gage readings.

## LOS ANGELES RIVER BASIN.

### GENERAL FEATURES.

Los Angeles River is formed by Tujunga, Pacoima, and other small creeks whose sources lie in the Sierra Madre northeast of the city of Los Angeles. These streams leave the mountains at a point about 25 miles above the city and enter the comparatively flat country of the San Fernando Valley, where, except at times of excessive flood, the waters disappear in the sand and gravel washes. At the lower end of this valley is a secondary range of hills, extending from east to west, and bed rock obstruction forces the waters to the surface to form what is known as Los Angeles River. Below this point the river flows through the flat country of the Los Angeles Valley and enters the Pacific near the town of Long Beach. At the city of Los Angeles it is joined by Arroyo Seco. This stream issues from the mountains on the west side of Pasadena Mesa, and passes through an opening in a granite spur known as Devils Gate. Between the point where it leaves the mountain and Devils Gate lies a broad river bottom, 2 miles long, composed of coarse material, into which the water sinks rapidly. In passing over this material the volume of flood water is diminished.

### LOS ANGELES RIVER AT LOS ANGELES, CAL.[1]

Los Angeles River was measured at the bridge near the old pigeon farm above junction with Arroyo Seco. The discharge at 11 a. m. January 19, 1916, was 1,308 second-feet. The maximum height of the flood during the storm was ascertained from an eye witness and from marks on the bank, as 4 feet higher than the stage of the river at the time the measurement was made. A velocity of 11.0 feet per second was used for computing the probable maximum discharge. The estimated maximum flow for the stream at this point was 7,268 second-feet.

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[1] Lippincott, J. B., memorandum concerning the floods of Jan. 17 and 18, 1916.

The following is a summary of measurements made January 18, 1916, for the flood flow between Dominguez Junction and Cerritos, of the water entering the Los Angeles and Long Beach harbors:[1]

| | Second-feet. |
|---|---|
| Main Cerritos bridge | 22,873 |
| Cota bridge (first opening to the west) | 1,816 |
| At pole No. 1006 (second opening) | 676 |
| Bridge No. 1463 | 1,057 |
| Bridge No. 1450 | 978 |
| Bridge No. 1433 | 3,240 |
| Bridge No. 1418 | 233 |
| Compton Creek | 240 |
| Total | 31,113 |

Practically half the flow was going to the east into the Long Beach Harbor and, as near as could be determined from the observations, half to the west into Wilmington Harbor. It is considered that the 1916 flood at this point was as great in volume as in 1914 and that it lasted longer.

### ARROYO SECO NEAR PASADENA, CAL.

**Location.**—Near south line of sec. 30, T. 2 N., R. 12 W. (unsurveyed), just below trail crossing at forest ranger's station in Angeles National Forest, about 3 miles above Devils Gate, 1½ miles above mouth of Millard Canyon, and 5½ miles northeast of Pasadena, Los Angeles County.

**Drainage area.**—16.4 square miles (measured on topographic maps).

**Elevation.**—About 1,450 feet above sea level.

**Records available.**—December 1, 1910, to January, 1916.

**Gage.**—Staff fastened to an alder on right bank 300 feet southeast of ranger's station.

**Discharge measurements.**—Made by wading below gage or from foot log.

**Channel and control.**—Composed of solid rock, gravel, and boulders; slightly shifting during high water.

**Extremes of discharge.**—1910-1915: Maximum stage recorded, 12.5 feet February 20, 1914 (discharge, 5,630 second-feet); minimum stage, below gage September 12 to 23, 1913 (discharge estimate, 0.1 second-foot).

**Maximum discharge in January, 1916.**—Crest of flood occurred at 9.30 a. m. January 17; gage height, 9.3 feet; discharge, 3,150 second-feet, or 192 second-feet per square mile.

**Accuracy.**—Gage read only 5 days in January. The high-water extension of the rating curve is based on measurement of slope and cross section of the channel. Curve well defined for medium and low stages.

*Discharge measurements of Arroyo Seco near Pasadena, Cal., during January, 1916.*

[Made by F. C. Ebert.]

| Date. | Gage height. | Discharge. |
|---|---|---|
| | *Feet.* | *Sec.-ft.* |
| Jan. 12 | 3.55 | 14 |
| 22 | 4.18 | 64 |

---

[1] Lippincott, J. B., memoranda concerning the floods of Jan. 17 and 18, 1916.

*Mean daily gage height, in feet, and discharge, in second-feet, of Arroyo Seco near Pasadena, Cal., for January, 1916.*

| Date. | Gage height. | Discharge. | Date. | Gage height. | Discharge. |
|---|---|---|---|---|---|
| Jan. 17 | 7.65 | [a]1,930 | Jan. 24 | 4.1 | 51 |
| 22 | 4.14 | 58 | 25 | 4.18 | 65 |
| 23 | 4.04 | 42 | | | |

[a] Maximum discharge Jan., 1916, see station description.

### ARROYO SECO[1] AT LOS ANGELES, CAL.

On January 19, 1916, the flood flow of the Arroyo Seco was measured at Avenue 20 Bridge in Los Angeles. The peak of the flood had passed. Soundings were made from the bridge at intervals of 5 feet. The velocity was ascertained by means of floats and found to be 6.0 feet per second. The discharge at 9.30 a. m. January 19, 1916, was 737 second-feet. From the statement of an eye witness and from water marks on the banks it was found that at the crest of the flood on the preceding days the water had been 4 feet higher than at the time of measurement. Accordingly, a section was computed for this higher level. The velocity at the higher stage was estimated to be 11.0 feet per second, which gives a maximum discharge for the storm at this point of 6,215 second-feet.

## SANTA CLARA RIVER BASIN.

### GENERAL FEATURES.

Santa Clara River has its source in Soledad Canyon in the north-central part of Los Angeles County. Its general course is westward, and it enters the Pacific Ocean about 3 miles southeast of Ventura. The principal tributaries are Castac, Piru, Sespe, and Santa Paula creeks, which enter from the north. During the low-water period the channels of these streams are usually dry at their junction with the main stream. For the lower 40 miles of its course the channel of Santa Clara River is broad and sandy. During the rainy season it is subject to very sudden and severe floods while for the remainder of the year the channel is practically dry.

### SESPE CREEK NEAR SESPE, CAL.

LOCATION.—At Bradfields Camp, in Santa Barbara National Forest, three-fourths of a mile below mouth of West Fork of Sespe Creek, 4½ miles above intake of Fillmore canal, and about 6½ miles northwest of Sespe, Ventura County

DRAINAGE AREA.—216 square miles (measured by Ralph Bennett, consulting engineer).

ELEVATION.—About 1,350 feet above sea level.

GAGE.—Painted on large boulder and on rock cliff on left bank.

DISCHARGE MEASUREMENTS.—Made from cable 250 feet above gage or by wading.

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[1] Lippincott, J. B., memoranda concerning the floods of Jan. 17 and 18, 1916.

**Channel and control.**—Gravel and large boulders; fairly permanent.

**Maximum discharge in January, 1916.**—The maximum stage reported was 18.7 feet (discharge 18,600 second-feet) on January 17 (time not given).

**Accuracy.**—Results considered good. Discharge measurements made after January 17 show that the high water caused a small amount of scour in the channel. Rating curves well defined.

**Cooperation.**—The gage-height record and discharge measurements were furnished by Sespe Light & Power Co.

*Discharge measurements of Sespe Creek near Sespe, Cal., for January, 1916.*

[Made by G. H. Killgore.]

| Date. | Gage height. | Discharge. | Date. | Gage height. | Discharge. | Date. | Gage height. | Discharge. |
|---|---|---|---|---|---|---|---|---|
| | *Feet.* | *Sec.-ft.* | | *Feet.* | *Sec.-ft.* | | *Feet.* | *Sec.-ft.* |
| Jan. 2 | 7.60 | 508 | Jan. 17 | 15.90 | [a] 10,100 | Jan. 19 | 9.20 | 1,550 |
| 3 | 6.70 | 292 | 17 | 18.70 | [a] 17,400 | 21 | 7.60 | 678 |
| 4 | 8.90 | 1,820 | 18 | 16.90 | [a] 13,700 | 27 | 12.90 | [a] 4,690 |

[a] Float measurement; coefficient of 0.85 used to reduce surface velocities to mean velocities.

*Mean daily discharge, in second-feet, of Sespe Creek near Sespe, Cal., for January, 1916.*

| Date. | Discharge. | Date. | Discharge. | Date. | Discharge. | Date. | Discharge. |
|---|---|---|---|---|---|---|---|
| Jan. 1 | 46 | Jan. 9 | 850 | Jan. 17 | 8,100 | Jan. 25 | 360 |
| 2 | 605 | 10 | 440 | 18 | 11,400 | 26 | 345 |
| 3 | 560 | 11 | 205 | 19 | 2,320 | 27 | 6,560 |
| 4 | 960 | 12 | 144 | 20 | 1,060 | 28 | 1,360 |
| 5 | 184 | 13 | 119 | 21 | 615 | 29 | 900 |
| 6 | 144 | 14 | 480 | 22 | 495 | 30 | 705 |
| 7 | 110 | 15 | 228 | 23 | 390 | 31 | 595 |
| 8 | 106 | 16 | 253 | 24 | 375 | | |

| Total run-off for month | | |
|---|---|---|
| | acre-feet | 81,200 |
| | depth in inches on drainage area | 7.04 |

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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Water-Supply Paper 427

# BIBLIOGRAPHY AND INDEX
# OF THE
# PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY RELATING TO GROUND WATER

BY

OSCAR E. MEINZER

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# ILLUSTRATION.

PLATE I. Map of the United States showing areas covered by the principal reports of the United States Geological Survey relating to ground water .......... In pocket.

# BIBLIOGRAPHY AND INDEX OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY RELATING TO GROUND WATER.

By Oscar E. Meinzer.

## INTRODUCTION.

### WORK DONE BY THE UNITED STATES GEOLOGICAL SURVEY.

The work of the United States Geological Survey includes investigations of the natural waters of the United States, both those which occur above and those which occur below the land surface. The waters below the surface are known as subsurface, subterranean, underground, or ground waters. According to the present usage of the Geological Survey the waters that occur below the surface in zones of saturation are called ground waters, and it is to these waters that the present bibliography and index applies.

In 1885 the Geological Survey published a paper by T. C. Chamberlin entitled "The requisite and qualifying conditions of artesian wells." But aside from this well-known paper it published practically nothing on the subject of ground water in the first 10 years of its existence except "Lists and analyses of mineral springs," by A. C. Peale; annual statistics on the production of mineral water, by A. C. Peale; and papers on the waters of Yellowstone National Park, by W. H. Weed and by F. A. Gooch and J. E. Whitfield.

In 1888, by act of Congress, the Geological Survey undertook irrigation investigations in the arid regions of the United States, which soon led to the problem of irrigation with artesian water. The Eleventh Annual Report, published in 1891, contains a section on artesian irrigation on the Great Plains and records of wells in 7 western States. In the Thirteenth Annual Report, published in 1893, there is a discussion by F. H. Newell on the occurrence and quantity of ground water in arid regions, with statistics on artesian wells and irrigation with well water in the United States. The need for more detailed information on the ground waters of the country became evident and resulted in a number of investigations. The first report dealing exclusively with eastern conditions was a paper by W J McGee, entitled "Potable waters of eastern United States," published in 1893. Systematic and extensive survey of the ground-water resources of the United States was begun in 1903, when the division of hydrology was organized, with N. H. Darton in charge of the work in the West and M. L. Fuller in charge of the work in the East. Since that time the ground-water survey has been carried steadily forward, and the methods of investigation have gradually been refined and standardized. From 1908 to 1912 the division was in charge of W. C. Mendenhall, and since 1912 it has been in charge of O. E. Meinzer.

Altogether a vast amount of accurate information of both scientific and economic value has been accumulated on the ground waters of the United States. A total of 609 papers have been published (in 454 volumes) which contain information on the subject of ground water, of which 307 papers (in 171 volumes) relate primarily to this subject. Many of these papers include detailed maps showing the ground-water conditions in specific areas. In addition to the published reports there is a great quantity of data as yet unpublished on file at the Geological Survey.

Although the aggregate of the work done on the ground-water resources of the United States is great and includes some work in every State, yet the country is so large that extensive regions are still very inadequately covered, and the amount of work that remains to be done is indefinitely great.

## SCOPE OF THE BIBLIOGRAPHY AND INDEX.

The present bibliography includes all publications prepared in whole or in part by the Geological Survey that treat any phase of the subject of ground water or any subject directly applicable to ground water, such as windmills, pumps, and other lifting devices, methods of water analysis, and methods of measuring the flow of water. It has a more limited scope than the bibliography by M. L. Fuller on ground-water papers published by the Geological Survey, 1879–1904 (Water-Supply Paper 120), in that it does not include papers that touch on the subject only incidentally. As in Fuller's bibliography, there is a brief abstract of each paper that is listed with special reference to its content on ground water. For papers dealing chiefly with other subjects page references are given to the parts relating to ground water.

The 454 volumes listed in this bibliography, comprise 207 water-supply papers, 22 annual reports, 4 monographs, 11 professional papers, 47 bulletins, 33 reports on mineral resources, 118 geologic folios, and 12 reports not published by the United States Geological Survey. Of the 171 volumes relating primarily to ground water 123 are water-supply papers.

The index includes only subjects relating to ground water. The areas covered by the reports are given under the individual States.

For more definite information on reports covering specific localities the index map (Pl. I, in pocket) should be consulted. The map does not, however, show all reports listed in the bibliography but only such as cover specific areas more or less thoroughly. Under the individual States in the index are given references to many reports which it was not practicable to show on the map.

## HOW TO OBTAIN THE PAPERS LISTED IN THE BIBLIOGRAPHY.

The publications of the United States Geological Survey listed in this bibliography, except the monographs and geologic folios, can be obtained free as long as the Survey's stock lasts. An asterisk (*) indicates that this stock has been exhausted. Many of the publications so marked may, however, be purchased at the prices indicated from the Superintendent of Documents, Washington, D. C. If there is an asterisk and no price is given the publication can no longer be obtained from the Government.

Monographs can be purchased at the prices indicated from the Superintendent of Documents, Washington, D. C.

Geologic folios can be purchased at the prices indicated, from the Director, United States Geological Survey, Washington, D. C., except those marked with an asterisk (*), which are out of stock and can no longer be obtained from the Government. Those priced at 5 cents have been more or less damaged by smoke or water.

The publications of the Geological Survey can be consulted in most of the principal libraries of the country and also at the branch offices of the Geological Survey in a number of the larger cities.

The cooperative reports listed on pages 45–47 are not published by the United States Geological Survey and are not distributed by the Federal Government.

# BIBLIOGRAPHY.

An asterisk (*) indicates that the publication referred to is out of stock (see section headed "How to obtain the papers listed in the bibliography," p. 3).

## WATER-SUPPLY PAPERS.

*1. Pumping water for irrigation, by H. M. Wilson. 1896. 57 pp., 9 pls.

Describes various pumps and curious and antiquated lifting devices used chiefly in India and Egypt; also engines, windmills, water wheels, and other devices for producing power for lifting water; also storage reservoirs for holding pumped water until needed for irrigation.

*2. Irrigation near Phoenix, Ariz., by A. P. Davis. 1897. 98 pp., 31 pls. 15c.

Describes chiefly irrigation with surface waters but also contains some well data and discusses briefly the quantity of underflow (pp. 86–92). For more comprehensive reports on the region see Water-Supply Papers 136 and 375–B.

*4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. 15c.

Describes the geography and geology, gives some well data, and discusses the artesian conditions and the irrigation prospects of an indefinite region in southeastern Washington.

*5. Irrigation practice on the Great Plains, by E. B. Cowgill. 1897. 39 pp., 12 pls.

Contains directions for constructing reservoirs for pumped well water (pp. 14–19).

*6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. 15c.

Covers a rectangular area comprising all of Meade County, nearly all of Seward, Haskell, and Gray counties, and parts of Ford and Finney counties. Describes the physiography, geology, water supplies, and irrigation developments of the area. Discusses the waters of the Dakota sandstone and of the Tertiary formations.

*7. Seepage water of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls. 10c.

Describes the water supplies of Cache Valley and the seepage waters in Ogden Valley. Discusses the loss of ground water by evaporation, transpiration, and seepage.

*8. Windmills for irrigation, by E. C. Murphy. 1897. 49 pp., 8 pls. 10c.

Describes the apparatus and methods used in making tests of windmills during the summer of 1896 in the vicinity of Garden City, Kans. Gives the results of these tests and draws conclusions.

*9. Irrigation near Greeley, Colo., by David Boyd. 1897. 90 pp., 21 pls.

Describes the water supplies, irrigation developments, and agricultural practice in the valley of Cache la Poudre River, a tributary of the South Platte. Discusses the legislative and judicial control of the water supplies (including ground water), the source and disposal of ground water, the use of ground water, the effects of alkali waters on soil, pumping of ground water, and artesian wells.

*10. Irrigation in Mesilla Valley, N. Mex., by F. C. Barker. 1898. 51 pp., 11 pls. 10c.

Describes primitive methods of irrigation and agriculture employed in the valley of the Rio Grande between Fort Seldon, N. Mex., and El Paso, Tex. Describes pumping for irrigation with windmills and steam engines.

*12. Underground waters of a portion of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls.

Covers an area that includes Lancaster, Seward, York, Fillmore, Hamilton-Clay, Hall, Adams, Buffalo, Kearney, and Phelps counties and parts of Saline, Gosper, and Dawson counties. Describes the physiography, geology, and ground waters of the area and discusses briefly the prospects for obtaining water from deep-seated formations.

*13. Irrigation systems in Texas, by W. F. Hutson. 1898. 68 pp., 10 pls.

Describes and discusses irrigation works and projects in Texas, considering both surface and ground waters as sources of supply. Superseded by Water-Supply Paper 71.

*14. New tests of certain pumps and water lifts used in irrigation, by O. P. Hood. 1898. 91 pp., 1 pl. 10c.

Discusses the mechanics and efficiency of reciprocating and of water lifts of various other types.

*17. Irrigation near Bakersfield, Cal., by C. E. Grunsky. 1898. 96 pp., 16 pls.

Describes irrigation with surface water and contains also a statement on early pumping from wells for irrigation at Lindsay, San Joaquin Valley, Cal. (p. 94).

*18. Irrigation near Fresno, Cal., by C. E. Grunsky. 1898. 94 pp., 14 pls. 10c.

Describes irrigation with surface water and contains a brief discussion of the loss of water from Kings River and Fresno Canal and its effect on the water table (pp. 71-79).

*20. Experiments with windmills, by T. O. Perry. 1899. 97 pp., 12 pls. 15c.

Gives data and discusses results of numerous laboratory experiments with wind-driven wheels. Describes the apparatus and methods used.

*21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls.

Gives well data by counties for the northern part of the State and contains two maps of Indiana and western Ohio, showing the character and depth of the glacial drift and its relation to water supplies.

*25. Water resources of the State of New York, Part II, by G. W. Rafter. 1899. pp. 105-200, 12 pls. 15c.

Discusses chiefly water storage and power and canal projects but also contains data in regard to seepage from canals (pp. 159-160, 173-178) and quantities of water yielded by the sand deposits of Long Island (pp. 191-198).

*26. Wells of southern Indiana, by Frank Leverett. 1899. 64 pp. 5c.

Gives well data by counties for the southern part of the State.

27. (See p. 47.)

28. (See p. 47.)

*29. Wells and windmills in Nebraska, by E. H. Barbour. 1899. 85 pp., 27 pls. 15c.

Describes home-made windmills, various other water-lifting devices, salt-water wells, and blowing and freezing wells; gives well data and promiscuous information in regard to ground water.

*30. Water resources of the Lower Peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls.

Discusses the use of water and the effects of quality with respect to the various uses. Describes the geology and ground-water conditions in the area covered.

*31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls. 10c.

Discusses the economic value of mineral waters and the interpretation and classification of water analyses; contains analyses of water from various geologic formations and generalizations in regard to them; also discusses sanitary conditions of drinking waters.

*34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 10 pls. 10c.

Covers a rectangular area that includes parts of Turner, Hutchinson, Bonhomme, Yankton, and Clay counties. Describes the geology and the surface and ground waters with special reference to the artesian water in the Dakota sandstone. Contains a geologic map and maps showing depths to bed rock, depths to the water at the base of the till, and depths to the artesian water. This area is also covered by Geologic Folios 96 and 97.

36. (See pp. 47-48.)

37. (See p. 48.)

39. (See p. 48.)

*41. The windmill; its efficiency and economic use, Part I, by E. C. Murphy. 1901. 72 pp., 14 pls. 5c.

See under Water-Supply Paper 42.

*42. The windmill; its efficiency and economic use, Part II, by E. C. Murphy. 1901. pp. 77–147, 2 pls. 10c.

Nos. 41 and 42 give a classification of windmills, describe early experiments with windmills and tests made by the writer, describe the apparatus and methods used in making these tests, and discuss the results of the tests.

*45. Water storage on Cache Creek, Cal., by A. E. Chandler. 1901. 48 pp., 10 pls. 15c.

Contains data in regard to wells and irrigation with ground water near Woodland, Sacramento Valley, Cal. (pp. 23–26).

50. Operations at river stations, 1900, Part IV. 1901. 96 pp.

Includes a section on "Computations of seepage in Colorado," pp. 299–306, in which are given data on seepage, chiefly seepage into rivers, and conclusions as to the relation of irrigation to seepage.

52. Operations at river stations, 1900, Part VI. 1901. pp. 495–575.

Contains a section entitled "Construction of wells in southern California" (pp. 497–498).

*53. Geology and water resources of Nez Perce County, Idaho, Part I, by I. C. Russell. 1901. 86 pp., 10 pls. 10c.

See under Water-Supply Paper 54.

*54. Geology and water resources of Nez Perce County, Idaho, Part II, by I. C. Russell. 1901. Pages 87–141.

Nos. 53 and 54 relate to an indefinite area in western Idaho including a part of Nez Perce County and to adjacent areas of Washington and Oregon. They describe briefly the physiography, geology, soils, water supplies, and mineral resources of the region.

The information on ground water, all of which is given in Water-Supply Paper 54, includes meager data with recommendations in regard to springs, "horizontal wells" or infiltration tunnels, and artesian wells. No. 54 also contains a short bibliography of artesian waters.

55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 68 pp., 7 pls. 10c.

Describes the geography, geology, and surface and ground waters of an area comprising about 50 square miles in the vicinity of Yakima. Discusses the artesian basins in detail and gives well data. The part of this area west of Yakima is also covered by Geologic Folio 86, which contains a more detailed geologic map and also contains a discussion of the artesian and other ground-water conditions.

*57. Preliminary list of deep borings in the United States, Part I (Alabama–Montana), by N. H. Darton. 1902. 60 pp. 5c.

See under Water-Supply Papers 61 and 149.

*58. Storage of water on Kings River, Cal., by J. B. Lippincott. 1902. 101 pp., 32 pls. 15c.

Contains discussions of ground water for irrigation and of alkali conditions and includes records of 854 wells (pp. 22–24, 53–88). Contains map (Pl. V) showing locations of wells listed in the table.

*59. Development and application of water near San Bernardino, Colton, and Riverside, Cal., Part I, by J. B. Lippincott. 1902. 95 pp., 11 pls.

See under Water-Supply Paper 60.

*60. Development and application of water near San Bernardino, Colton, and Riverside, Cal., Part II, by J. B. Lippincott. 1902. pp. 96–141. 15c.

Nos. 59 and 60 give descriptions of pumping plants and of ground-water supplies. No. 60 contains records of 412 wells in Redlands quadrangle and of 478 wells in San Bernardino quadrangle. No. 59 includes a topographic map showing contours of water table, areas of artesian flow in 1897 and 1900, irrigated areas and locations of wells for which records are given.

*61. Preliminary list of deep borings in the United States, Part II (Nebraska–Wyoming), by N. H. Darton. 1902. 67 pp. 5c.

Nos. 57 and 61 contain tabular data in regard to wells and other borings more than 400 feet deep. They give information as to the depths, diameters, and yields of the wells, the head, temperature, and quality of the water, and purposes for which the boring was done. The data are given by States, and the States are arranged alphabetically. The States from Alabama to Montana, inclusive, are covered by No. 57, and the States from Nebraska to Wyoming, inclusive, by No. 61. A revised edition for all States was published in 1905 as Water-Supply Paper 149.

62. Hydrography of the southern Appalachian Mountain region, Part I, by H. A. Pressey. 1902. 95 pp., 25 pls.

Contains a paragraph on large springs in the Watauga River basin (p. 82).

*66. Operations at river stations, 1901, Part II. 1902. 188 pp. 10c.

Contains a brief description of the springs, flowing wells, and ground-water conditions in the vicinity of Carrizo Springs, Tex. Includes an analysis of the Carrizo Springs mineral water (p. 63).

*67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls. 15c.

Discusses the origin, depth, and amount of ground waters, the porosity and permeability of rocks and soils; the causes, rates, and laws of the movements of ground water, the surficial and deep zones of circulation, the recovery of water by wells, and the shape and position of the water table. Gives simple methods of measuring the yield of flowing wells. Describes artesian wells at Savannah, Ga.

70. Geology and water resources of the Patrick and Goshen Hole quadrangles, in eastern Wyoming and western Nebraska, by G. I. Adams. 1902. 50 pp., 11 pls. 15c.

Describes the geology and contains some information on springs and wells in these quadrangles.

71. Irrigation systems of Texas, by T. U. Taylor. 1902. 137 pp., 9 pls. 10c.

Discusses the principal irrigation systems, giving special attention to the irrigation of rice. Contains data in regard to numerous springs and artesian and other wells.

75. Report of progress of stream measurements for the calendar year 1901, by F. H. Newell. 1903. 246 pp., 13 pls.

Contains, on pages 204 and 205, records of discharge of 33 flowing wells in Moxie Valley, near Yakima, Wash.

77. The water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls. 10c.

Describes the geography, geology, and water resources of the island of Molokai, including springs and wells. Describes the occurrence of water in lava and its quality as affected by the sea. Contains a discussion and estimate of the quantity of ground water available for irrigation.

*78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls. 5c.

Describes briefly the geology of a part of the Snake River plains in Canyon and Owyhee counties, Idaho, and Malheur and Harney counties, Oreg. Discusses the conditions on which artesian flow depends and describes springs and wells in the Lewis, Otis, Harney, and Whitehorse artesian basins. Describes artesian wells in alluvial deposits and discusses the size of drill holes, the methods of casing, the preservation of well records, and the importance of laws to govern the use of artesian waters. Gives a list of publications bearing on artesian waters.

84. Report of progress of stream measurements for the calendar year 1902, by F. H. Newell, Part III, Western Mississippi River and western Gulf drainage. 1903. 200 pp.

Contains a brief description of Barton Springs, near Austin, Tex. (pp. 152, 153). See also Water-Supply Papers 132 and 174.

85. (See p. 48.)

89. Water resources of the Salinas Valley, Cal., by Homer Hamlin. 1904. 91 pp., 12 pls. 15c.

Includes data in regard to ground water and pumping plants and a map showing the area of artesian flow and the areas irrigated with water obtained from wells.

90. Geology and water resources of part of the lower James River valley, S. Dak., by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls. 35c.

Describes the geology, surface waters, and artesian and other ground waters of a rectangular area comprising Davison, Hanson, Sanborn, Beadle, and Miner counties and parts of Kingsbury, Jerauld, Aurora, and McCook counties. Includes a geologic map of the area and maps showing areas of artesian flow, depths to Dakota sandstone, head of artesian water, depths to bed rock, and depths to water at the base of the till. The area is also described in Geologic Folios 99, 100, 113, and 114.

91. The natural features and economic development of the Sandusky, Maumee, Muskingum, and Miami drainage areas in Ohio, by B. H. and M. S. Flynn. 1904. 130 pp. 10c.

Includes descriptions of numerous public water supplies obtained from wells and springs (pp. 58-124).

98. (See p. 48.)

*99. Report of progress of stream measurements for the calendar year 1903. Part III, Western Mississippi River and western Gulf of Mexico drainage, by J. C. Hoyt. 1904. 422 pp., 1 pl. 25c.

Contains on pages 235-237 a description and discharge record of Meramec Spring, near Meramec, Mo. See also Water-Supply Papers 131, 173, and 209. Contains, on page 321, the discharge records of 16 springs in Oklahoma.

101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls. 20c.

Describes the geology and ground-water conditions of the area, gives data in regard to artesian wells, and outlines methods of well drilling, pumping, and rice irrigation. Includes 23 analyses of ground water.

102. Contributions to the hydrology of eastern United States, 1903; M. L. Fuller, geologist in charge. 1904. 522 pp. 30c.

Contains a list of publications of the United States Geological Survey relating to ground water, with special reference to springs. Gives an account of the organization and of the work of the division of hydrology (ground water). Contains notes on wells, springs, and general water resources, arranged by counties, in the following States:

Maine, by W. S. Bayley. Contains records of 224 wells and 130 springs and analyses of 3 well waters and of 3 spring waters (pp. 27-55).

New Hampshire, by J. M. Boutwell. Contains records of 35 wells and 107 springs and analyses of 9 well waters and 12 spring waters (pp. 56-72).

Vermont, by G. H. Perkins. Contains a table giving data in regard to the water supplies of Vermont towns, contains also 111 partial analyses of waters from wells, springs, streams, and lakes and records of 44 wells and 90 springs (pp. 73-93).

Massachusetts, by W. O. Crosby and Laurence LaForge. Contains records of 162 wells and 40 springs and analyses of 7 well waters and 17 spring waters (pp. 94-118).

Rhode Island, by W. O. Crosby. Contains records of 24 wells and 12 springs and analyses of 2 well waters and 3 spring waters (pp. 120-126).

Connecticut, by H. E. Gregory. Contains records of about 470 wells and 84 springs and analyses of 19 well waters and 19 spring waters (pp. 127-168).

New York, by F. B. Weeks. Contains records of 371 wells and 228 springs and analyses of 14 well waters (pp. 169-206).

Georgia, by S. W. McCallie. Contains a table giving data in regard to water supplies of cities and villages in the State. Contains records of 90 wells and 100 springs and a table giving the yields of 14 springs. Includes analyses of water from 1 well and 1 spring (pp. 207-237).

Florida, by M. L. Fuller. Contains records of 242 wells and 43 springs and analyses of 11 well waters and 9 spring waters. Gives the yields of some very large springs (pp. 238-275).

Alabama, by E. A. Smith. Contains notes on numerous wells by counties (pp. 276-331).

Mississippi, by L. C. Johnson and E. C. Eckel. Contains records of 265 wells (pp. 332-357).

Tennessee, by L. C. Glenn. Contains records of 78 wells (pp. 357-367).

102. Contributions to the hydrology of eastern United States, 1903—Continued.

Kentucky, by L. C. Glenn. Contains records of 16 wells and 2 analyses of artesian water (pp. 369–373).

Arkansas, by A. H. Purdue. Contains records of 96 wells and 33 springs and analyses of 3 well waters (pp. 374–388).

Missouri, by E. M. Shepard. Contains records of 105 wells and 112 springs and analyses of 13 well waters and 34 spring waters (pp. 389–440). Includes brief papers on wells of Joplin and vicinity, by W. S. T. Smith (pp. 404–409), and the water supply of Livingston County, by R. Hawkins (pp. 410–416).

Minnesota, by C. W. Hall. Contains records of about 800 shallow wells, about 200 deep wells, and 76 springs; includes an analysis of water from a spring at Mankato (pp. 441–488).

Lower Michigan, by W. F. Cooper. Contains records of 198 wells and 31 springs and analyses of 11 well waters and 15 spring waters (pp. 489–512).

104. The underground waters of Gila Valley, Ariz., by W. T. Lee. 1904. 71 pp., 5 pls. 10c.

Describes the topography and geology of the Gila Valley between The Buttes, 12 miles east of Florence, and the mouth of Salt River; treats of the source, amount, and quality of water in the valley fill and the methods of recovering this water; includes well data and water analyses.

105. The water powers of Texas, by T. U. Taylor. 1904. 116 pp., 17 pls.

Gives data regarding Hackberry Springs (2 miles northwest of Toyah Lake) and Santa Rosa Spring, near Santa Lucia, in Pecos County (pp. 14, 15).

106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls. 5c.

Describes the geology and the streams, springs, wells, and public water supplies of an area comprising the Germantown, Norristown, Philadelphia, and Chester quadrangles. Discusses artesian conditions and prospects in the crystalline rocks, the Triassic formations, and the formations of the Coastal Plain. The area is also described in Geologic Folio 162, which contains considerable information on ground water.

108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls. 15c.

Contains analyses of ground waters and discussions of the quality of these waters.

110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1905. 211 pp., 5 pls. 10c.

Contains the reports in the following list. Most of those covering specific areas do not include any maps.

Description of underflow meter used in measuring the velocity and direction of underground water, by Charles S. Slichter (pp. 17–31).

The California or "stovepipe" method of well construction, by Charles S. Slichter (pp. 32–36).

Approximate methods of measuring the yield of flowing wells, by Charles S. Slichter (pp. 37–42).

Corrections necessary in accurate determinations of flow from vertical well casings, from notes furnished by A. N. Talbot (pp. 43–44).

Experiment relating to problems of well contamination at Quitman, Ga., by S. W. McCallie (pp. 45–54).

The new artesian water supply at Ithaca, N. Y., by F. L. Whitney (pp. 55–64).

Drilled wells of the Triassic area of the Connecticut Valley, by W. H. C. Pynchon (pp. 65–94).

Triassic rocks of the Connecticut Valley as a source of water supply, by M. L. Fuller (pp. 95–112).

Spring system of the Decaturville dome, Camden County, Mo., by E. M. Shepard (pp. 113–125).

Water resources of the Fort Ticonderoga quadrangle, Vt. and N. Y., by T. N. Dale (pp. 126–129).

Water resources of the Taconic quadrangle, N. Y., Mass., and Vt., by F. B. Taylor (pp. 130–133).

Water resources of the Watkins Glen quadrangle, N. Y., by R. S. Tarr (pp. 134–140). The ground-water conditions of this quadrangle are described more fully in Geologic Folio 169.

Water resources of the central and southwestern highlands of New Jersey, by Laurence La Forge (pp. 141–155).

110. Contributions to the hydrology of eastern United States, 1904—Continued.

Water resources of the Chambersburg and Mercersburg quadrangles, Pa., by G. W. Stose (pp. 156-158). The ground-water conditions of these quadrangles are described more fully in Geologic Folio 170.

Water resources of the Curwensville, Patton, Ebensburg, and Barnesboro quadrangles, Pa., by F. G. Clapp (pp. 159-163). The ground-water conditions of the Barnesboro and Patton quadrangles are also briefly described in Geologic Folio 189, and those of the Ebensburg quadrangle in Geologic Folio 133. The ground waters of the Curwensville, Barnesboro, and Patton quadrangles are also briefly described in Bulletin 531-d.

Water resources of the Elders Ridge quadrangle, Pa., by R. W. Stone (pp. 164, 165). The ground-water conditions of this quadrangle are also described in Bulletin 256 (with geologic map) and in Geologic Folio 123.

Water resources of the Waynesburg quadrangle, Pa., by R. W. Stone (pp. 166, 167). The ground-water conditions of this quadrangle are also described in Geologic Folio 121.

Water resources of the Accident and Grantsville quadrangles, Md., by G. C. Martin (pp. 168-170). The ground-water conditions of these quadrangles are also described in Geologic Folio 160.

Water resources of the Frostburg and Flintstone quadrangles, Md. and W. Va., by G. C. Martin (pp. 171-173).

Water resources of Cowee and Pisgah quadrangles, N. C., by H. S. Gale (pp. 174-176). The ground-water conditions of the Pisgah quadrangle are described also in Geologic Folio 147.

Water resources of the Middleboro-Harlan region of southeastern Kentucky, by G. H. Ashley (pp. 177-178).

Summary of the water supply of the Ozark region in northern Arkansas, by G. I. Adams (pp. 179-182).

Notes on the hydrology of Cuba, by M. L. Fuller (pp. 183-200).

111. Preliminary report on the underground waters of Washington, by Henry Landes. 1905. 85 pp., 1 pl. 10c.

Describes briefly by counties the deep wells, springs, and municipal water supplies of the State.

*112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1905. 55 pp., 7 pls. 5c.

Describes in detail the methods and apparatus used in making measurements of the rate and volume of underflow and gives the results of underflow tests made in the valley of Los Angeles River in 1902 and 1903.

113. The disposal of strawboard and oil-well wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls. 5c.

The second part of this paper describes briefly the geology and ground waters of the region about Marion, Ind., and the contamination of rock wells and streams by waste oil and brine.

*114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1905. 285 pp., 18 pls. 25c.

Contains a paper entitled "Occurrence of underground waters," by M. L. Fuller, in which are discussed the source, quantity, and temperature of ground waters, the permeability and storage capacity of water-bearing formations, the recovery of water through springs and wells, the conditions that produce artesian flow and the general ground-water conditions in eastern United States (pp. 18-40).

Contains also brief reports on ground water in the following States, each of which includes a bibliography:

Maine, by W. S. Bayley (pp. 41-56). Includes analyses of 35 spring waters.

New Hampshire, by M. L. Fuller (pp. 57-59).

Vermont, by G. H. Perkins (pp. 60-67). Includes a sketch map of the State, showing water-bearing deposits and analyses of 3 spring waters.

Massachusetts and Rhode Island, by W. O. Crosby (pp. 68-75).

Connecticut, by H. E. Gregory (pp. 76-81). Includes a sketch map of the State, showing the rock formations.

New York, by F. B. Weeks (pp. 82-92). Includes a sketch map of the State, showing the rock formations.

New Jersey, by G. N. Knapp (pp. 93-103). Includes a sketch map of the State, showing the ground-water provinces, and 5 geologic sections, showing the water-bearing formations of the Coastal Plain.

Pennsylvania, by M. L. Fuller (pp. 104-110). Includes a sketch map of the State, showing the main geologic systems.

*114. Underground waters of eastern United States—Continued.

Delaware, by N. H. Darton (pp. 111–113). Includes geologic sections showing water-bearing formations.

Maryland, by N. H. Darton and M. L. Fuller (pp. 114–123). Includes geologic sections showing water-bearing formations.

District of Columbia, by N. H. Darton and M. L. Fuller (pp. 124–126). Includes geologic sections showing water-bearing formations.

Virginia, by N. H. Darton and M. L. Fuller (pp. 127–135). Includes geologic sections showing water-bearing formations.

North Carolina, by M. L. Fuller (pp. 136–139).

South Carolina, by L. C. Glenn (pp. 140–152). Includes geologic sections showing water-bearing formations.

Georgia, by S. W. McCallie (pp. 153–158). Includes a sketch map of the State, showing areas of artesian flow.

Florida, by M. L. Fuller (pp. 159–163).

Alabama, by E. A. Smith (pp. 164–170). Includes a sketch map of the State, showing ground-water conditions.

Mississippi, by L. C. Johnson (pp. 171–178). Includes a geologic sketch map of the State.

Louisiana and southern Arkansas, by A. C. Veatch (pp. 179–187). Includes sketch maps showing ground-water conditions.

Northern Arkansas, by A. H. Purdue (pp. 188–197). Includes a geologic sketch map and sections of the area.

Tennessee and Kentucky, by L. C. Glenn (pp. 198–208).

Missouri, by E. M. Shepard (pp. 209–219). Includes sketch maps showing the geology and and ground-water conditions of the State.

Iowa, by W. H. Norton (pp. 220–225).

Minnesota, by C. W. Hall (pp. 226–232).

Wisconsin, Northern Peninsula of Michigan and the portion of Illinois north of the Carboniferous deposits, by Alfred R. Schultz (pp. 232–241). Includes a sketch map of the region showing the outcrops of the "Potsdam" and St. Peter sandstones.

Lower Michigan, compiled from report by A. C. Lane (pp. 242–247). Includes a geologic sketch map and a section of the area.

Illinois, by Frank Leverett (pp. 248–257). Includes a geologic sketch map and a section of the State.

Indiana, by Frank Leverett (pp. 258–264). Includes sketch maps of the State, showing the geology, the depth of the glacial drift, and the relation of wells to depths of drift.

Ohio, by Frank Leverett (pp. 265–270). Includes sketch maps of the State showing the geology, the depths of the glacial drift, and the relation of wells to the depth of drift.

West Virginia, by M. L. Fuller (pp. 271–272).

116. Water problems of Santa Barbara, Cal., by J. B. Lippincott. 1905. 99 pp., 8 pls. 10c.

Deals chiefly with surface waters but contains data on deep city wells and collecting tunnel and analysis of tunnel water (pp. 33–42, 57).

118. Geology and water resources of a portion of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls. 5c.

Describes briefly the geology of the Columbia Plains and the Kittitas Valley, gives information in regard to the streams, springs, and wells, and discusses the artesian prospects.

120. Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879–1904, by M. L. Fuller. 1905. 128 pp. 10c.

Lists all papers that contain information on ground water. Gives brief abstracts of these papers in regard to ground water, with page references for papers dealing mainly with other subjects. Contains an index of the papers listed in so far as they relate to ground water.

*122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp. 5c.

Defines and classifies ground waters and gives common-law rules and State legislative acts relating to their use.

*123. Geology and underground water conditions of the Jornada del Muerto, N. Mex., by C. R. Keyes. 1905. 42 pp., 9 pls. 15c.

This report is superseded by Water-Supply Paper 188.

127. (See p. 48.)

130. (See p. 48.)

131. Report of progress of stream measurements for the calendar year 1904, Part VIII, Platte, Kansas, Meramec, Arkansas, and Red River drainages, by M. C. Hinderlider and J. C. Hoyt. 1905.

**Contains, on pages 123-125, a description and discharge record for Meramec Spring, near Meramec, Mo. See also Water-Supply Papers 99, 173, and 209.**

132. Report of progress of stream measurements for the calendar year 1904, Part IX, Western Gulf of Mexico and Rio Grande drainages, by T. U. Taylor and J. C. Hoyt. 1905. 132 pp., 2 pls.

**Contains descriptions of the following springs in Texas: Lipan and Kickapoo springs near San Angelo (p. 43); Barton and Mormon springs, near Austin (pp. 44 and 45); Toyah Spring, at Toyahville (pp. 121 and 122); and Santa Rosa Spring near Fort Stockton (p. 122). (See also p. 127.)**

133. (See p. 48.)

135. (See p. 48.)

136. Underground waters of Salt River valley, Ariz., by W. T. Lee. 1905. 196 pp., 23 pls. 25c.

**Describes the geology of that part of the valley in which Phoenix and Mesa are situated. Gives well records and discusses the quantity and chemical character of the ground waters, the duty of water for irrigation, and the cost of pumping. Contains maps showing the geology and the position of the water table.**

*137. Development of underground waters in the eastern coastal-plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls. 35c.

**Describes the ground-water conditions and the irrigation systems in the Anaheim and Santa Ana quadrangles in Los Angeles and Orange counties. Discusses the effects of development and drought on ground-water levels, contains records of 2,765 wells, and includes maps showing original areas of artesian flow, areas of artesian flow in 1904, ground-water levels, irrigated lands, and locations of wells and pumping plants. Includes also a general map of the "Valley of southern California," showing contours of the water table, original areas of artesian flow, and areas of artesian flow in 1904.**

*138. Development of underground waters in the central coastal-plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls. 25c. See under Water-Supply Paper 139.

**Describes the ground-water conditions and the irrigation systems in the Downey and Las Bolas quadrangles, in Los Angeles and Orange counties. Discusses the effects of development and drought on ground-water levels, contains records of 3,323 wells, and includes maps showing original areas of artesian flow, areas of artesian flow in 1904, ground-water levels, irrigated lands, and locations of wells and pumping plants. Contains also the general map mentioned under Water-Supply Paper 137.**

*139. Development of underground waters in the western coastal-plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 8 pls. 25c.

**Describes the ground-water conditions and the irrigation systems in the Santa Monica and Redondo quadrangles, in Los Angeles County. Discusses the effects of development and drought on changes in ground-water levels, contains records of 2,097 wells, and includes maps showing original areas of artesian flow, areas of artesian flow in 1904, ground-water levels, irrigated lands, and locations of wells and pumping plants. Contains also the general map mentioned under Water-Supply Paper 137.**

140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1905. 122 pp., 15 pls. 15c.

**Discusses the capacity of sand to transmit water, describes the under-flow meter devised by the author and laboratory experiments on the flow of water through sands and gravels, and gives results of measurements of underflow in Rio Hondo, San Gabriel, and Mohave River valleys, Cal., and on Long Island, N. Y. Discusses specific capacities of wells, gives results of tests of wells and pumping plants in the Rio Grande valley in New Mexico and Texas and the Arkansas Valley in Kansas, and describes the "stovepipe" method of well construction.**

141. Observations on the ground waters of the Rio Grande valley, by C. S. Slichter. 1905. 83 pp., 5 pls. 5c.

Describes investigation of the underflow in the valley of the Rio Grande in Texas and New Mexico, gives details of tests of pumping plants near El Paso, Tex., in Mesilla Valley, N. Mex., and near Berino, N. Mex., and gives analyses of well waters and data concerning wells at and near El Paso.

*142. The hydrology of San Bernardino Valley, Cal., by W. C. Mendenhall. 1905. 124 pp., 12 pls. 25c.

Describes the source, circulation, quantity, temperature, and chemical character of the ground water, gives records of 890 wells, and contains maps showing changes in areas of artesian flow and in ground-water levels, and locations of wells, pumping plants, and irrigated lands. This paper, like Nos. 137, 138, 139, and 219, also contains a general map of the of southern California," showing contours of water table, original areas of artesian f areas of artesian flow in 1904.

144. The normal distribution of chlorine in the natural waters of New Yo New England, by D. D. Jackson. 1905. 31 pp., 5 pls. 10c.

Discusses the content of sodium chloride in coast and inland waters and its value in ing pollution of streams and wells. Describes the solutions and methods used in determ of chlorine. Contains maps showing the normal distribution of chlorine in surface and waters in the New England States and New York, and tables giving data on which the maps are based.

145. Contributions to the hydrology of eastern United States, 1905; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls. 10c.

Contains the reports in the following list. Most of those covering specified areas do not include any maps.

Hydrologic work in eastern United States and publications on ground waters, by M. Fuller (pp. 9-29).

The drainage of ponds into drilled wells, by R. E. Horton (pp. 30-39).

Two unusual types of artesian flow, by M. L. Fuller (pp. 40-45).

Construction of so-called fountain and geyser springs, by M. L. Fuller (pp. 46-50).

A convenient gage for determining low artesian heads, by M. L. Fuller (pp. 51, 52).

Water resources of the Catatonk area, N. Y., by E. M. Kindle (pp. 53-57). The ground-water conditions in this quadrangle are also described in Geologic Folio 169.

Water resources of the Pawpaw and Hancock quadrangles, W. Va., Md., and Pa., by G. W. Stose and G. C. Martin (pp. 58-63). The ground-water conditions in these quadrangles are also described in Geologic Folio 179.

Water resources of the Nicholas quadrangle, W. Va., by G. H. Ashley (pp. 64-66).

Water resources of the Mineral Point quadrangle, Wis., by U. S. Grant (pp. 67-73). The ground-water conditions in this quadrangle are also described in Geologic Folio 145.

Water resources of the Joplin district, Mo.-Kans., by W. S. T. Smith (pp. 74-83). The ground-water conditions in this quadrangle are also described in Geologic Folio 148, but analyses are given only in the water-supply paper.

Water resources of the Winslow quadrangle, Ark., by A. H. Purdue (pp. 84-87). The ground-water conditions in this quadrangle are also described in Geologic Folio 154.

Water resources of the contact region between the Paleozoic and Mississippi embayment deposits in northern Arkansas, by A. H. Purdue (pp. 88-119).

Water resources of the Portsmouth-York region, N. H. and Maine, by G. O. Smith (pp. 120, 128).

A ground-water problem in southeastern Michigan, by M. L. Fuller (pp. 129-147).

Water supplies at Waterloo, Iowa, by W. H. Norton (pp. 148-155).

Water supply from glacial gravels near Augusta, Maine, by G. O. Smith (pp. 156-160).

Water-supply from the delta type of sand plain, by W. O. Crosby (pp. 161-178).

Waters of a gravel-filled valley near Tully, N. Y., by G. B. Hollister (pp. 179-184).

Notes on certain hot springs of the southern United States, by W. H. Weed (pp. 185-206).

Notes on certain large springs of the Ozark region, Mo. and Ark., compiled by M. L. Fuller (pp. 207-210).

146. Proceedings of second conference of engineers of the Reclamation Service, with accompanying papers, compiled by F. H. Newell, chief engineer. 1905. 267 pp. 15c.

Contains a brief account of the organization of the hydrographic [water resources] branch, including the division of hydrology [ground water]. Includes the following papers relating to ground water, drilling methods, and pumping for irrigation.

Pumping underground water in southern California, by F. C. Finkle.
Diamond-drill methods, by G. A. Hammond.
Underground waters of southern California, by W. C. Mendenhall.
Cost of power for pumping irrigating water, by H. A. Storrs.

*148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls. 20c.

Covers only the original Territory of Oklahoma, not the eastern part of the State. Describes the topography and geology and the streams, springs, and wells; discusses artesian conditions, outlines the water supplies by counties; treats of irrigation from reservoirs, springs, and wells; and gives 154 analyses of well waters and a table containing records of 261 wells. Includes a geologic map.

149. Preliminary list of deep borings in the United States, second edition with additions, by N. H. Darton. 1905. 175 pp. 10c.

Gives location, depth, diameter, yield, water level, and other available information concerning wells 400 feet or more in depth; includes all wells listed in Water-Supply Papers 57 and 61. Contains some data in regard to every State in the United States, arranged alphabetically by States and counties. Mentions principal publications relating to deep borings.

*150. Weir experiments, coefficients, and formulas, by R. E. Horton. 1906. 189 pp., 38 pls. 15c.

Superseded by Water-Supply Paper 200.

*151. Field assay of water, by M. O. Leighton. 1905. 77 pp., 4 pls. 10c.

Describes apparatus, reagents, and methods for rapid field determinations of turbidity, color, iron, hardness, carbonates, bicarbonates, sulphates, chlorides, and calcium in water.

152. A review of the laws forbidding pollution of inland waters in the United States (second edition), by E. B. Goodell. 1905. 149 pp. 10c.

Includes laws relating to wells and springs.

*153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906. 90 pp., 3 pls. 15c.

Discusses the origin and extent of the underflow, the fluctuation of ground-water level, and the chemical composition of the water. Gives results of underflow measurements and tests of the rate of evaporation of ground water. Gives summaries and details of pumping tests and analyses of river and well waters.

*154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls. 10c.

Describes the topography and geology and the streams and springs, discusses the ground-water conditions and irrigation, and gives detailed data by counties. Includes a geologic map.

*155. Fluctuation of the water level in wells, with special reference to Long Island, N. Y., by A. C. Veatch. 1906. 83 pp., 9 pls. 25c.

Gives data on ground-water levels and discusses fluctuations due to rainfall, evaporation, barometric changes, temperature changes in rivers, changes in lake levels, tidal changes, irrigation, the construction of dams, ground-water developments, deforestation, cultivation of the soil, drainage, and other causes.

*157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls. 20c.

Describes the geology and the ground-water conditions and gives numerous well records. Includes maps showing depths to ground water and areas of artesian flow.

158. Preliminary report on the geology and underground waters of the Roswell artesian area, N. Mex., by C. A. Fisher. 1906. 29 pp., 9 pls. 15c.

Describes the geology and ground-water conditions of the artesian basin which extends along Pecos River from Roswell to Lake McMillan. Discusses the area and extent of the artesian basin, the source, quantity, pressure, quality, and conservation of the artesian water, and the irrigation with this water. Gives well records and analyses and contains maps showing the area of artesian flow and the intake area.

159. Summary of the underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906. 86 pp., 6 pls. 20c.

Describes the geology and the ground-water conditions of the State. Gives notes on wells by counties, records of deep wells, and chemical analyses. Includes a geologic map (Pl. I) and a map showing ground-water conditions (Pl. V).

*160. Underground-water papers, 1906; M. L. Fuller, geologist in charge. 1906. 104 pp., 1 pl.

Gives an account of work done in 1905 and lists of publications relating to ground waters; also contains the following reports:

Significance of the term "artesian," by M. L. Fuller (pp. 9-15).
Representation of wells and springs on maps, by M. L. Fuller (pp. 16-18).
Occurrence of water in crystalline rocks, by E. E. Ellis (pp. 19-28).
Flowing-well districts in the eastern part of the northern peninsula of Michigan, by Frank Leverett (pp. 29-53).
Drainage of wet lands in Arkansas by wells, by A. F. Crider (pp. 54-58).
Total amount of free water in earth's crust, by M. L. Fuller (pp. 59-72).
Use of fluorescein in the study of underground waters, by R. B. Dole (pp. 73-85).
Peculiar mineral waters from crystalline rocks of Georgia, by M. L. Fuller (pp. 86-91).
Problems of water contamination, by Isaiah Bowman (pp. 92-95).
Instances of improvement of water in wells, by M. L. Fuller (pp. 96-100).

*163. Bibliographic review and index of underground-water literature published in the United States in 1905, by M. L. Fuller, F. G. Clapp, and B. L. Johnson. 1906. 130 pp. 15c.

Lists practically all papers that contain any information on ground water; includes brief abstracts with respect to ground water, giving page references for reports dealing mainly with other subjects; contains index with respect to ground-water subjects of papers listed.

*164. Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois, by L. C. Glenn. 1906. 173 pp., 7 pls. 25c.

Describes the topography and geology, discusses mineral waters and artesian conditions, and outlines the water resources by counties. Contains maps showing the geology and the head of the artesian water.

168. (See p. 48.)

170. Report of progress of stream measurements for the calendar year 1905, Part VI, Great Lakes and St. Lawrence River drainages, by R. E. Horton, F. W. Hanna, and J. C. Hoyt. 1906. 116 pp., 1 pl.

Contains, on pages 24 and 25, a description and a one-year record of discharge of Reeds Springs, near Albion, Mich.

173. Report of progress of stream measurements for the calendar year 1905, Part IX, Meramec, Arkansas, Red, and lower western Mississippi River drainages, by M. C. Hinderlider, J. M. Giles, and J. C. Hoyt. 1906. 105 pp., 1 pl.

Contains, on page 17, a description and discharge record of Meramec Spring, near Meramec, Mo. See also Water-Supply Papers 99, 131, and 209.

174. Report of progress of stream measurements for the calendar year 1905, Part X, western Gulf of Mexico and Rio Grande drainages, by T. U. Taylor and J. C. Hoyt. 1906. 113 pp., 1 pl.

Describes Bartons Springs, near Austin, Tex. (pp. 30, 31).

177. (See p. 48.)

*181. Geology and water resources of Owens Valley, Cal., by W. T. Lee. 1906. 28 pp., 6 pls. 15c.

Outlines the geology and ground-water conditions, gives well records, and discusses briefly the artesian prospects, the utilization of ground waters by installation of pumping and power plants, reservoir sites, and the significance of undrained lakes as registers of climate. See also Water-Supply Paper 294.

*182. Flowing wells and municipal water supplies in the southern portion of the southern peninsula of Michigan, by Frank Leverett and others. 1906. 292 pp., 5 pls. 50c.

See under Water-Supply Paper 183.

*183. Flowing wells and municipal water supplies in the middle and northern portions of the southern peninsula of Michigan, by Frank Leverett and others. 1907. 393 pp., 5 pls. 50c.

Nos. 182 and 183 describe in general the geology and ground-water conditions of the areas covered and give details by counties concerning flowing wells and municipal supplies. They contain numerous analyses and several geologic and artesian-water maps.

*184. The underflow of the South Platte Valley, by C. S. Slichter and H. C. Wolff. 1906. 42 pp. 5c.

Describes investigations of velocity, direction, and quantity of underflow at Ogalalla, Nebr. gives chemical analyses of the water, and discusses disadvantages of underflow canals or infiltration ditches. Describes also investigations at North Platte, Nebr., and gives suggestions for the construction of small pumping plants.

*188. Water resources of the Rio Grande Valley, N. Mex., and their development, by W. T. Lee. 1907. 59 pp., 10 pls. 20c.

Describes the topography and geology, reservoir sites, and the water resources of the valley. Gives the well data and outlines the ground-water conditions in the Santa Fe, Albuquerque, Belen, Jornada, La Mesa, and Mesilla districts. Discusses the origin, course, and quantity of the ground water, its character, and its utilization by means of wells and infiltration ditches. Contains several analyses of river and well waters and includes a topographic map of Mesilla Valley, showing depths to ground water.

*190. Underground waters of the Coastal Plain of Texas, by T. U. Taylor. 1907. 73 pp., 3 pls. 15c.

Describes the ground waters by counties; gives many well records and analyses; includes a map showing locations of artesian wells.

*191. The geology and water resources of the western portion of the Panhandle of Texas, by C. N. Gould. 1907. 70 pp., 7 pls. 15c.

Describes the topography and geology, the springs, streams, and shallow and deep-seated ground waters, and the utilization of the waters for irrigation. Gives detailed information by counties and includes a geologic map.

*193. The quality of surface waters in Minnesota, by R. B. Dole and F. F. Wesbrook. 1907. 171 pp., 7 pls. 25c.

Relates chiefly to surface waters but contains scattered notes on wells used for public supplies throughout the State, a table of data in regard to these wells (pp. 146–149), and a brief discussion of the comparative value of surface and ground waters (pp. 151–153).

*195. Underground waters of Missouri, their geology and utilization, by E. M. Shepard. 1907. 224 pp., 6 pls. 30c.

Describes the topography and geology of the State and discusses the water supplies by districts and counties; gives statistics of city water supplies, analyses of water, and many well sections and records; includes a map of the State, showing the locations of flowing and nonflowing deep wells.

197. (See p. 48.)

*199. Underground water in Sanpete and central Sevier valleys, Utah, by G. B. Richardson. 1907. 63 pp., 6 pls. 25c.

Describes the geology of the area and the sources, distribution, recovery, and quality of the ground waters; gives detailed descriptions and tabulated data concerning springs and wells; includes a map showing the geology and the depths to ground water.

*200. Weir experiments, coefficients, and formulas, by R. E. Horton. 1907. 195 pp., 38 pls. 35c.

Revision of Water-Supply Paper 150. A treatise on the theory of weirs, with tables and curves based on experiments.

*209. Surface water supply of lower western Mississippi River drainage, 1906, by R. I. Meeker and J. M. Giles. 1907. 79 pp., 2 pls. 15c.

Contains, on pages 21 and 22, a description and discharge record of Meramec Spring, near Meramec, Mo. See also Water-Supply Papers 99, 131, and 173. Contains, on page 74, discharge records of Antelope, Buffalo, and Sulphur springs, near Sulphur, Okla.

212. (See pp. 48–49.)

*213. Surface water supply of California, 1906, by W. B. Clapp, with a section on ground-water levels in southern California, by W. C. Mendenhall. 1907. 219 pp., 4 pls. 25c.

Gives the results of a series of measurements of water levels in wells made during 1904, 1905, and 1906 (pp. 189–205). Wells widely distributed over the various basins of southern California were selected in order that the data would give a basis for conclusions as to the fluctuations of the water table in each of these basins.

214. (See p. 49.)

*215. Geology and water resources of a portion of the Missouri River valley in northeastern Nebraska, by G. E. Condra. 1908. 59 pp., 11 pls. 40c.

Describes the geology, streams, springs, and shallow and artesian wells in Boyd, Knox, Cedar, Dixon, and Dakota counties, and in a part of Holt County; includes maps showing the geology and the artesian-water conditions; contains information on "blowing wells."

*216. Geology and water resources of the Republican River valley and adjacent areas, Nebraska, by G. E. Condra. 1907. 71 pp., 13 pls. 15c.

Describes the geography, geology, and surface and ground waters in Dundy, Hitchcock, Redwillow, Furnas, Harlan, Franklin, Webster, Nuckolls, Thayer, and Jefferson counties; includes a geologic map; contains information on "blowing wells."

*217. Water resources of Beaver Valley, Utah, by W. T. Lee. 1908. 57 pp., 1 pl. 10c.

Describes the geography, geology, streams, springs, and seepage waters of the eastern part of Beaver County. Gives data in regard to deep wells in the Beaver, Greenville, Adamsville, Minersville, and Milford districts, and at railroad stations between Beryl and Lynn. Discusses possible developments of additional irrigation supplies from surface and underground sources. Describes the quality of the water and contains field assays and laboratory analyses.

*219. Ground waters and irrigation enterprises in the foothill belt, southern California, by W. C. Mendenhall. 1908. 180 pp., 9 pls. 50c.

Covers the Pasadena, Pomona, and Cucamonga quadrangles, which lie south of the San Gabriel Mountains between Los Angeles and San Bernardino. Describes the geography, geology, and ground-water conditions, discusses fluctuation in ground-water levels and the conservation of the water supply, and gives the results of measurements of water levels in 1904, 1905, and 1906. Describes irrigation systems and gives records of 1,044 wells. Contains maps showing original areas of artesian flow, areas of artesian flow in 1904, ground-water levels, irrigated lands, and locations of wells and pumping plants. Contains also the general map that is described under Water-Supply Paper 142 and is included with Water-Supply Papers 137, 138, and 139.

*220. Geology and water resources of a portion of south-central Oregon, by G. A. Waring. 1908. 86 pp., 10 pls. 20c.

Describes the geography and geology, and the streams, lakes, and ground waters in the valleys of Goose Lake, Abert Lake, Chewaucan Marsh, Summer Lake, Silver Lake, Christmas Lake, Alkali Lake, and in Warner Valley and several smaller valleys lying chiefly in Lake County. Gives analyses of waters and of alkali in soil and includes a geologic map.

221. Geology and water resources of the Great Falls region, Mont., by C. A. Fisher. 1909. 89 pp., 7 pls. 20c.

Describes the geography and geology, and the surface waters, ground waters, and artesian conditions in an irregular area comprising parts of Cascade, Teton, Fergus, Chouteau, and Lewis and Clark counties. Discusses municipal water supplies, the chemical character of the water, water powers, irrigation, and agriculture; gives analyses of water; includes maps showing the geology, the locations of artesian wells, etc.

*222. Preliminary report on the ground waters of San Joaquin Valley, Cal., by W. C. Mendenhall. 1908. 52 pp., 1 pl. 10c.

Describes the geography, geology, and surface and ground waters of the entire valley. Discusses the origin, circulation, quantity, accessibility, and development of the ground waters; gives notes on the water supplies by counties; and includes a map showing areas of artesian flow and contours of the water table. Superseded by Water-Supply Paper 398.

*223. Underground waters of southern Maine, by F. G. Clapp, with records of deep wells, by W. S. Bayley. 1909. 268 pp., 24 pls. 55c.

Covers an area that lies almost entirely south of the 45th parallel. Describes the physiography, drainage, water-bearing rocks, the quantity, source, disposition, and temperature of the ground waters, and the recovery of water from springs, collecting galleries, tunnels, and wells. Discusses well-drilling methods and costs, municipal water supplies, and the quality of the ground waters. Gives detailed data for each county and records of deep wells. Includes a geologic map of southern Maine, and several diagrams showing the relative composition of waters from different kinds of rock.

*224. Some desert watering places in southeastern California and southwestern Nevada, by W. C. Mendenhall. 1909. 98 pp., 4 pls. 20c.

Describes the physical features of the region, gives hints on desert traveling and on finding water in desert places, describes main routes of travel, and gives detailed descriptions of springs, wells, and other watering places. Includes a map of the region showing roads and watering places.

*225. Ground waters of the Indio region, Cal., with a sketch of the Colorado Desert, by W. C. Mendenhall. 1909. 56 pp., 12 pls. 20c.

Describes the geography, geology, precipitation, and drainage, and the source, character, and development of ground waters in the Colorado Desert, with special reference to the Indio region, which is the name applied to the artesian basin extending from the vicinity of Indio to the Salton Sea. Contains a table of well data and a map of the Indio region showing areas of artesian flow, irrigated lands, and locations of wells and pumping plants.

*227. Geology and underground waters of South Dakota, by N. H. Darton. 1909. 156 pp., 15 pls. 40c.

Describes the geology and water horizons of the State, and discusses by counties the deep wells and well prospects. Gives notes on the construction and management of artesian wells. Includes maps showing the geology and the artesian conditions.

230. (See p. 49.)

*231. Geology and water resources of the Harney Basin region, Oreg., by G. A. Waring. 1909. 93 pp., 5 pls. 25c.

Describes the geography, geology, surface waters, ground waters, and artesian conditions of the Harney, Catlow, Alvord, Whitehorse, and Malheur River basins, which lie chiefly in Harney County. Discusses the conservation of the water supply, the temperatures of ground waters, and well drilling methods and costs. Includes a geologic map of the area.

232. Underground water resources of Connecticut, by H. E. Gregory, with a study of the occurrence of water in crystalline rocks, by E. E. Ellis. 1909. 200 pp., 5 pls. 20c.

Describes the physiography and geology, and the circulation, quantity, temperature, quality, and contamination of the ground water of the State. Discusses the water in the crystalline rocks, the Triassic sandstones and traps, and the glacial drift. Discusses also the methods of constructing wells and the character and use of the springs. Gives records of wells and springs and analyses of ground waters. Includes detailed descriptions of the towns of Warren, North Haven, and Branford Point.

233. Water resources of the Blue Grass region, Ky., by G. C. Matson, with a chapter on the quality of the waters, by Chase Palmer. 1909. 223 pp., 3 pls. 20c.

Describes the physiography, geology, soils, and water resources of an area covering 30 counties in the north-central part of Kentucky. Discusses the source, occurrence, quantity, and recovery of ground water, the artesian conditions, the collection and storage of rain water, and the municipal water supplies, the industrial uses and comparative hardness of the ground waters, and the various medicinal and table waters. Contains detailed data in regard to each county, and numerous well records and water analyses. Includes a geologic map of the area.

*234. Papers on the conservation of water resources. 1909. 96 pp., 2 pls. 15c.

Contains a paper on underground waters, by W. C. Mendenhall.

236. The quality of surface waters in the United States, Part I, Analyses of waters east of the one hundredth meridian, by R. B. Dole. 1909. 123 pp. 10c.

Contains analyses of surface waters exclusively, but includes a description of analytical methods, an outline of methods for expressing analytical results, and a discussion of the probable accuracy of analyses that are applicable to ground waters as well as to surface waters. Describes methods for the following determinations: Turbidity, total suspended solids, total dissolved solids, silica, iron, calcium, magnesium, sodium and potassium, carbonates, bicarbonates, sulphates, chlorine, nitrates, total acidity, and total iron. Also gives directions for the preparation of the necessary solutions.

240. Geology and water resources of the San Luis Valley, Colo., by C. E. Siebenthal. 1910. 128 pp., 13 pls. 25c.

Describes the geography and geology, and the artesian and other waters of the valley. Gives detailed data regarding the springs and the flowing and nonflowing wells, and discusses adequacy and permanence of the artesian supply, variations in flow, and temperature, quality and uses of the water, well-drilling methods and costs, and approximate methods for measuring the discharge of flowing wells. Contains several analyses and a map showing the area of artesian flow, the gas fields, and the area of colored water.

247. (See p. 49.)

250. (See p. 49.)

251. Surface-water supply of the United States, 1907–8, Part XI, California. 1910. 363 pp., 7 pls. 35c.

Contains a section (pp. 338–348) on "fluctuations in ground-water levels in the valley of southern California, by W. C. Mendenhall, in which are given results of measurements of depths to the water level in typical wells during 1907–8. These measurements were a continuation of the work reported in Water-Supply Paper 213. Contains also records of the discharge of springs as follows: Fish Springs, Seeley Springs, and Black Rock Springs, Cal. (p. 333); Bettles Rest Springs, Oreg. (p. 337); Fords Springs, and Olene Springs, Cal. (p. 338).

252. (See p. 49.)

254. The underground waters of north-central Indiana, by S. R. Capps, with a chapter on the chemical character of the waters, by R. B. Dole. 1910. 279 pp., 7 pls. 40c.

Covers the following 19 counties: Boone, Carroll, Cass, Clinton, Elkhart, Fulton, Grant, Hamilton, Hancock, Hendricks, Howard, Kosciusko, Madison, Marion, Marshall, Miami, St. Joseph, Tipton, and Wabash. Describes the geography and geology, the sources, movements, occurrence, and quantity of ground water and the methods of constructing wells and of lifting water. Describes in detail, for each county, the ground-water conditions and the water supplies for cities, villages, and rural districts. Discusses the methods of making water analyses and of expressing the results, the mineral constituents of natural waters, the influence of these constituents upon domestic, industrial, and medicinal uses of the water, and methods of purification. Compares the chemical composition of the waters in different geologic formations in the area and gives numerous analyses and field assays. Contains maps showing the distribution of rock formations and surface deposits, the thickness of the surface deposits, and the areas of artesian flow.

*255. Underground waters for farm use, by M. L. Fuller. 1910. 58 pp., 17 pls. 15c.

Discusses the various kinds of water-bearing formations and the relative safety of supplies from each. Describes different types of springs and their protection from pollution. Discusses dug and drilled wells with respect to their location, yield, cost, and safety from pollution. Discusses also cisterns and combination wells and cisterns.

256. Geology and underground waters of southern Minnesota, by C. W. Hall, O. E. Meinzer, and M. L. Fuller. 1911. 406 pp., 18 pls. 60c.

Covers Bigstone, Swift, Kandiyohi, Meeker, Wright, Anoka, and Washington counties and all of Minnesota south of these counties. Discusses the physiography, geologic history, geologic formations and their water-bearing capacities, artesian conditions, mineral quality of the ground waters, types of wells, methods of finishing wells in sand, methods of drilling in quartzite, "blowing" and "breathing" of wells, freezing of wells and other phenomena due to variations in atmospheric pressure, drainage into wells, and municipal water supplies. Gives detailed data, by counties, concerning the yield, head, and quality of water. Includes numerous analyses of water and maps showing the thickness and character of surface deposits, the depths to granitic rocks and Sioux quartzite, the distribution of water-bearing formations, the areas of artesian flow, and the quality of ground waters; also diagrams showing geographic variations in the quality of the waters from surface deposits and bedrocks.

*257. Well-drilling methods, by Isaiah Bowman. 1911. 139 pp., 4 pls. 15c.

Discusses briefly ground water in the United States and water-bearing formations; gives a history of well drilling in Asia, Europe, and the United States; and describes the various methods of drilling and the machinery used. Discusses the difficulties encountered in sinking wells, the flooding of oil wells, the contamination of water wells and methods of preventing contamination, the capacity of wells and methods of testing capacity, methods of measuring the depth of wells and of detecting the defection of drill holes, and the cost of sinking wells.

*258. Underground-water papers, 1910, by M. L. Fuller, F. G. Clapp, G. C. Matson, Samuel Sanford, and H. C. Wolff. 1911. 123 pp., 2 pls. 15c.

Contains the following papers:

Drainage by wells, by M. L. Fuller (pp. 6-22).

Freezing of wells and related phenomena, by M. L. Fuller (pp. 23-31).

Occurrence and composition of well waters in the slates of Maine, by F. G. Clapp (pp. 32-39).

Occurrence and composition of well waters in the granites of New England, by F. G. Clapp. (pp. 40-47).

Pollution of underground waters in limestone, by G. C. Matson (pp. 48-56).

Protection of shallow wells in sandy deposits, by M. L. Fuller (pp. 57-65).

Composition of mineral springs in Maine, by F. G. Clapp (pp. 66-74).

Saline artesian waters of the Atlantic Coastal Plain, by Samuel Sanford (pp. 75-86).

Magnetic wells, by M. L. Fuller (pp. 87-93).

Underground waters near Manassas, Va., by F. G. Clapp (pp. 94-97).

The utilization of the underflow near St. Francis, Kans., by H. C. Wolff (pp. 98-119).

259. The underground waters of southwestern Ohio, by M. L. Fuller and F. G. Clapp, with a discussion of the chemical character of the waters, by R. B. Dole. 1912. 228 pp., 9 pls. 35c.

Covers the following counties: Adams (western half), Brown, Butler, Clark, Clermont, Clinton, Darke (southern part), Greene, Hamilton, Highland (western half), Miami (southern part), Montgomery, Preble, and Warren. Describes the topography and geology, the water-bearing formations, the source, occurrence, and head of the water, and the municipal water supplies. Gives detailed information in regard to ground-water conditions by counties. Discusses methods of making water analyses and of expressing the results, mineral constituents of natural water and their effects with respect to its use for domestic, industrial, and medicinal purposes, and methods of purifying water. Gives numerous analyses and field assays. Includes maps showing the rock formations, the surface deposits, the thickness of surface deposits, structure contours, and areas of artesian flow. The chapter on the chemical character of the water is nearly the same as the chapter on the same subject in Water-Supply Paper 254.

*260. Preliminary report on the ground waters of Estancia Valley, N. Mex., by O. E. Meinzer. 1910. 33 pp. 5c.

Describes briefly the ground-water conditions in the valley and discusses the use of ground water for irrigation. Includes analyses but no maps. This report is superseded by Water-Supply Paper 275.

271. (See p. 49.)

273. Quality of the water supplies of Kansas, by H. N. Parker, with a preliminary report on stream pollution by mine waters in southeastern Kansas, by E. H. S. Bailey. 1911. 375 pp., 1 pl. 30c.

Describes the geology, ground water, and artesian basins of the State; discusses the significance of mineral constituents and classification of water; gives details concerning quality of ground water by counties and surface water by drainage basins; contains numerous assays and analyses of surface and ground waters; includes a geologic map of the State.

274. Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and industrial application of water analyses, by Herman Stabler. 1911. 188 pp. 15c.

Contains analyses of surface waters exclusively, but the discussion of industrial application of water analyses which it includes is as pertinent for ground waters as for surface waters. This discussion introduces "reacting coefficients" and "reacting values" and develops formulae for calculating, from analysis, the soap-consuming power of the water, the amount of softening constituents that it requires, the extent of foaming, priming, and corrosion that it will produce in boilers, the amount of scale and the hardness of the scale that it will deposit in boilers, and its quality for irrigation.

275. Geology and water resources of Estancia Valley, N. Mex., with notes on ground-water conditions in adjacent parts of central New Mexico, by O. E. Meinzer. 1911. 89 pp., 14 pls. 20c.

Describes the physiography, geology, soil, and climate of the valley, and discusses the source and disposal of ground water, the water table, artesian conditions, yields of wells, quantity of ground water available, quality of ground water, storage of storm waters, use of ground water for irrigation, types of wells, windmills, cost of pumping, and the alkali problems. Contains tables giving depths to water level in wells and analyses and assays of water from wells and springs. Contains also brief reports on physiography, geology, soil, ground water, and irrigation in Encino and Pinos Wells basins, and notes on wells at Vaughan. Includes maps showing physiography and Pleistocene and Recent geology, depths to the water table, and amount of chlorides and sulphates found in the ground waters.

*276. Geology and underground waters of northeastern Texas, by C. H. Gordon. 1911. 78 pp., 2 pls. 10c.

Covers an area comprising Bowie, Camp, Cass, Delta, Franklin, Hopkins, Lama, Morris, Red River, and Titus counties. Describes the geography and geology, and the artesian and other waters found in the various formations. Describes the water resources by counties. Gives tables of well data and analyses of ground waters and includes a geologic map of the area.

277. Ground water in Juab, Millard, and Iron counties, Utah, by O. E. Meinzer. 1911. 162 pp., 5 pls. 25c.

Describes briefly the physiography, geology, precipitation, soil, vegetation, streams, and industrial development, occurrence of water in bed rock and in unconsolidated sediments, artesian conditions, springs, the quality of ground waters, irrigation, construction of wells, and watering places on routes of travel. Describes in more detail Juab, Round, Little, Sage, Dog, Fernow, and Tintic valleys, the Tintic mining district, Pavant and Lower Beaver valleys, Old River Bed, Cherry Creek, the Drum, and Swasey Wash regions, Sevier Desert, Wah Wah Valley, Sevier Lake bottoms, White, Fish Springs, Snake, Parowan, and Rush Lake valleys and the Escalante Desert. Contains several water analyses.

278. Water resources of Antelope Valley, Cal., by H. R. Johnson. 1911. 92 pp., 7 pls. 25c.

Describes the drainage, climate, and physiography, and the water-bearing and non water-bearing formations of an area in Kern, Los Angeles, and San Bernardino counties. Discusses the artesian and other ground waters, the chemical character of the ground waters, certain fallacies as to the origin and quantity of artesian water, and the present and future development of the underground supplies. Contains a table of well data and a few chemical analyses, and includes a map showing water-bearing and nonwater-bearing formations and the area of artesian flow.

288. (See p. 49.)

289. (See p. 49.)

293. Underground-water resources of Iowa, by W. H. Norton, W. S. Hendrixson, H. E. Simpson, O. E. Meinzer, and others. 1912. 994 pp., 18 pls. 70c.

Describes the topography, climate, and geology of the State, the occurrence of water in the various geologic formations, the artesian phenomena and the yields of artesian wells, the chemical composition of the ground waters, the municipal, domestic and industrial water supplies, and methods of drilling wells. Discusses corrosion of well casings and boilers and the deposition of scale in boilers. Gives a classification of mineral waters. Contains numerous sections of wells and about 400 water analyses. Gives detailed information concerning ground waters and city and village supplies by districts and counties. Includes maps showing the glacial and rock geology, structure contours of water-bearing formations, locations of deep wells, head of artesian water, and quality of ground water. Also includes numerous geologic sections showing depths to the principal water-bearing formations. Describes a method of casing deep wells with cement (p. 562).

294. An intensive study of the water resources of a part of Owens Valley, Cal., by C. H. Lee. 1912. 135 pp., 30 pls. 55c.

Relates to the Independence region, a segment of Owens Valley that is relatively isolated with respect to water supplies. Describes the underground reservoir of this region and the drainage basin tributary to it. Presents quantitative data on precipitation, stream flow, percolation into the underground reservoir from precipitation, streams, irrigation, and flood waters, evaporation and transpiration from soils in experimental tanks with various depths to water level, fluctuations of the water table, height of capillary rise of ground water, areas with specified depths to the water table within the range of capillary rise, and discharge from springs. Analyzes the data and calculates the annual intake and discharge of the underground reservoir and the available supply of ground water. Includes maps showing depths to ground water and other hydrologic features and also includes numerous diagrams. The results of the tank experiments and their application in estimating the discharge of ground water in closed desert basins are of general interest.

298. (See p. 49.)

*300. Water resources of California, Part III, Stream measurements in the Great Basin and Pacific coast river basins, by H. D. McGlashan and H. J. Dean. 1913. 956 pp., 4 pls. .55c.

Gives discharge records of springs and wells in California as follows: Grover Hot Springs (p. 198), Black Rock Springs (p. 393), Seeley Springs (p. 394), Slanson well (p. 680), Shasta Little Springs (p. 913), Anna Creek Spring (p. 914), Bettles Rest Springs (p. 915), Barclay Springs (p. 915), Fords Spring (p. 917), and Olene Springs (p. 918).

310. (See p. 49.)

314. (See p. 49.)

*315. The purification of public water supplies, by G. A. Johnson. 1913. 84 pp. 8 pls. 10c.

Includes a brief discussion of ground waters for municipal supplies; also information on methods of purification that are more or less applicable to ground waters.

316. Geology and water resources of a portion of south-central Washington, by G. A. Waring. 1913. 46 pp., 1 pl. 5c.

Covers an area of about 5,000 square miles comprising Benton County and parts of Franklin, Grant, Yakima, and Klickitat counties. Describes the climate, vegetation, physiography, and geology; discusses shallow and artesian waters and irrigation enterprises in Sunnyside and Reservation valleys, Horse Heaven Plateau, and the Columbia River plains, and irrigation along lower Yakima River; gives tabulated data concerning wells and springs; includes a geologic map.

*317. Geology and underground waters of the Wichita region, north-central Texas, by C. H. Gordon. 1913. 88 pp., 2 pls. 10c.

Covers Archer, Baylor, Clay, Foard, Hardeman, Haskell, Jack, Knox, Montague, Throckmorton, Wichita, Wilbarger, and Young counties. Describes the physiography and geology, the occurrence and quality of ground waters and their relation to rock structure, the effects of barometric changes on water levels, and the water-bearing formations; gives detailed information by counties; contains numerous sections of wells and water analyses; includes a geologic map.

318. Water resources of Hawaii, 1909–1911, by W. F. Martin and C. H. Pierce. 1913. 552 pp., 15 pls. 50c.

Describes chiefly surface-water supplies, but contains brief notes on ground-water supplies and data on the discharge of springs, infiltration tunnels, flowing wells, and pumped wells on several islands, as follows: Kauai, pumped wells (p. 144); Oahu, springs, pumped wells, and flowing wells (pp. 163, 187–196); Maui, pumped wells (pp. 258, 331–332); Hawaii, springs and infiltration tunnels (p. 408). Gives sections of wells on Oahu (pp. 191–193).

*319. Geology and ground waters of Florida, by G. C. Matson and Samuel Sanford. 1913. 445 pp., 17 pls. 60c.

Describes the characteristic upland, lowland, and coastal features of the State—the springs, lakes, caverns, sink holes, natural bridges, terraces, sand dunes, coral reefs, bars, inlets, tidal runways, pine lands, swamps, keys, and ocean currents. Describes in detail the geologic formations, the source, quantity, depth, circulation, and recovery of artesian and other ground waters. Gives detailed information concerning ground-water conditions and water supplies by counties. Contains numerous well sections and tables of well data and includes maps showing the geology and the Pleistocene terraces of the State.

320. Geology and water resources of Sulphur Spring Valley, Ariz., by O. E. Meinzer and F. C. Kelton, with a section on agriculture, by R. H. Forbes. 1912. 231 pp., 15 pls. 45c.

Covers Sulphur Spring Valley and contains a small amount of information on San Pedro, San Simon, and San Bernardino valleys. Describes the physiography, the drainage, the geology, with special reference to the Quaternary deposits in the valley, the seasonal and geographic distribution of the precipitation, the occurrence and level of the ground water, the flowing and nonflowing wells, the quality of ground waters with relation to derivative rocks, water levels, and underground circulation, the effects of quality on irrigation and other uses, the distribution of alkali in the soil, the relation of the alkali to the water table and to the drainage, and the relation of zones of vegetation to water supply and other geographic controls. Contains detailed data in regard to tests of 20 pumping plants and describes a portable weir used in making these tests. Gives the history of agriculture in the valley and discusses agricultural methods. Contains analyses of water and of alkali in the soil and includes maps showing the geology, vegetation, depths to ground water, elevation of the water table, quality of water, and alkali in soil.

326. (See p. 49.)

331. Surface water supply of the United States, 1912, Part X, Pacific coast basins in California, by H. D. McGlashan and G. C. Stevens. 1914. 442 pp., 2 pls. 30c.

Contains records for 1909 to 1912, inclusive, of water levels in the series of wells for which water-level data are given in Water-Supply Papers 213 and 251, with an introductory note by W. C. Mendenhall (pp. 425–434).

332. (See p. 49.)

333. Ground water in Boxelder and Tooele counties, Utah, by Everett Carpenter. 1913. 90 pp., 2 pls. 10c.

Covers all of Boxelder County and Tooele, Rush, and Skull valleys in Tooele County. Describes briefly the geography, geology, water in bedrock and in unconsolidated sediments, artesian conditions, springs, and quality of ground waters; gives detailed information by valleys; contains numerous assays of water; includes a guide to watering places on routes of travel and maps showing locations of flowing and nonflowing wells, springs, and roads.

*335. Geology and underground waters of the southeastern part of the Texas Coastal Plain, by Alexander Deussen. 1914. 365 pp., 9 pls. 55c.

Covers that part of the Coastal Plain of Texas occupied by the outcrop of Cenozoic rocks east of Brazos River and south of a line extending east and west through Jefferson, in Marion County. Describes the physiography, stratigraphy, geologic structure, occurrence of ground water, springs, artesian systems, and quality of water with reference to various uses and in relation to the geologic formations; gives detailed information by counties; contains numerous well sections and water analyses; includes maps showing the geology of the region and the structure contours and areas of artesian flow for the seven principal artesian reservoirs.

336. Water resources of Hawaii, 1912, by C. H. Pierce and G. K. Larrison. 1914. 392 pp. 50c.

Relates chiefly to surface waters, but contains data in regard to pumpage of wells and seepage of ditches on the Island of Kauai (p. 99), discharge of springs and flowing wells and fluctuations of water levels in wells on the Island of Oahu (p. 128), pumpage of wells on the Island of Maui (pp. 209–211), and of springs on the Island of Hawaii (p. 381).

338. Springs of California, by G. A. Waring. 1915. 410 pp., 13 pls. 60c.

Describes the physical features of California and discusses natural waters with respect to mineral analyses, source and amount of dissolved substances, therapeutic and other properties, temperature, and classification. Gives detailed descriptions of springs, particularly those which yield mineral waters or are used as centers of recreation or health resort. Contains numerous analyses and includes maps showing the geology of the State and the locations of hot, carbonated, and sulphur springs.

*340. Stream-gaging stations and publications relating to water resources, 1885–1913, by B. D. Wood. 1916. 195 pp. 15c.

Includes papers dealing with ground water. Issued also in separate chapters, as follows:

*(*a*) Part I. North Atlantic coast drainage basins, pp. 1–19.
(*b*) Part II. South Atlantic coast and eastern Gulf of Mexico drainage basins, pp. 21–30.
(*c*) Part III. Ohio River basin, pp. 31–42.
(*d*) Part IV. St. Lawrence River basin, pp. 43–52.
(*e*) Part V. Hudson Bay and upper Mississippi River drainage basins, pp. 53–61.
(*f*) Part VI. Missouri River basin, pp. 63–81.
(*g*) Part VII. Lower Mississippi River basin, pp. 83–93.
(*h*) Part VIII. Western Gulf of Mexico drainage basins, pp. 95–104.
(*i*) Part IX. Colorado River basin, pp. 105–116.
(*j*) Part X. The Great Basin, pp. 117–129.
*(*k*) Part XI. Pacific coast basins in California, pp. 131–146.
*(*l*) Part XII. North Pacific slope drainage basins, pp. 147–195.

341. Underground waters of the Coastal Plain of Georgia, by L. W. Stephenson and J. O. Veatch, and a discussion of the quality of the waters, by R. B. Dole. 1915. 539 pp., 21 pls. 50c.

Describes the physiography and geology, the source, quantity, and disposition of water supplies, the artesian and nonartesian waters, the quality and use of water from springs and wells, and the stratigraphic distribution of the ground water. Gives detailed information by counties. Discusses the quality of the water in relation to industrial, domestic, and medicinal uses, the purification of water, and the composition of surface waters, and of ground waters in relation to geologic formations, geographic position, and depth. Contains many well sections and water analyses and includes maps showing the geology, the areas of artesian flow and the locations and depths of wells.

343. Geology and water resources of Tularosa Basin, N. Mex., by O. E. Meinzer and R. F. Hare. 1915. 317 pp., 19 pls. 40c.

Covers a large area in south-central New Mexico between the Rio Grande and Pecos valleys, and also contains data in regard to the vicinity of El Paso, Tex. Describes the physiography and geology and gives data on precipitation and its seasonal and geographic distributions. Discusses the water in the valley fill in regard to intake zones, occurrence, disposal, yield, artesian head, methods of constructing wells, and quality of the water in relation to derivative rocks, water table, and water-bearing beds and with respect to its use for drinking, cooking, washing, steam making, and irrigation. Discusses likewise the water in Cretaceous and Carboniferous strata and in igneous rocks. Describes the soil and native vegetation in relation to water supplies, the irrigation from streams, springs, flood waters, and wells, the railroad and public water supplies. Contains a guide to watering places on routes of travel, and tables of well data, analyses of water and soil, and distances between watering places. Includes maps showing the geology, vegetation, depths to water, contours of the water table, and locations of watering places and connecting roads.

*345. Contributions to the hydrology of the United States, 1914; N. C. Grover, chief hydraulic engineer. 1915. 225 pp., 17 pls. 30c.

Issued also in separate chapters. The following chapters relate to ground water:

(*a*) Preliminary report on ground water for irrigation in the vicinity of Wichita, Kans., by O. E. Meinzer (pp. 1–9).

(*b*) Ground water for irrigation in the vicinity of Enid, Okla., by A. T. Schwennesen (pp. 11–23, Pl. I). Includes a note on ground water for irrigation on the Great Plains, by O. E. Meinzer.

*345. Contributions to the hydrology of the United States, 1914—Continued.

(*c*) Underground water of Luna County, N. Mex., by N. H. Darton (pp. 25-40, Pl. II). Includes the results of five pumping tests made by A. T. Schwennesen.

(*d*) Ground water for irrigation in the valley of North Fork of Canadian River near Oklahoma City, Okla., by A. T. Schwennesen (pp. 41-51, Pl. III).

(*g*) The water resources of Butte, Mont., by O. E. Meinzer (pp. 79-126, Pls. VII-VIII).

(*h*) Ground- water resources of the Niles cone and adjacent areas, Cal., by W. O. Clark (pp. 127-168, Pls. IX-XVII).

All except No. 345-a include maps showing ground-water conditions. No. 345-h contains numerous records of water levels in wells and an estimate of ground-water recharge in 1912-13 and 1913-14 based on fluctuations of the water table. It includes a series of graphs showing fluctuations of the water table and the source of the ground water.

358. Water resources of the Rio Grande Basin, 1888-1913, by Robert Follansbee, H. J. Dean, W. W. Follett, and G. A. Gray, 1915. 725 pp., 3 pls.

Contains data on seepage of water into and out of streams, and discussions of the data (pp. 679-694).

359. (See p. 49.)

360. (See p. 49.)

362. (See p. 49.)

364. Water analyses from the laboratory of the United States Geological Survey, tabulated by F. W. Clarke. 1914. 44 pp. 5c.

Contains 203 miscellaneous analyses of waters from rivers, lakes, wells, springs, and mines, which were made at various times in the chemical laboratory of the United States Geological Survey. Includes analyses of waters from wells, springs, or mines in the following 25 States: Arkansas, Arizona, California, Colorado, Florida, Illinois, Iowa, Kentucky, Maine, Michigan, Mississippi, Missouri, Montana, Nevada, New Mexico, North Carolina, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, West Virginia, and Wyoming.

365. Ground water in southeastern Nevada, by Everett Carpenter. 1915. 86 pp., 5 pls. 15c.

Covers an area of about 17,000 square miles in Clark, Lincoln, White, Pine, and Nye counties, including the vicinities of Geyser, Lund, Barnes, and Duckwater, on the north, and the vicinities of Sharp, Hiko, Alamo, and Indian Springs, on the west. Describes briefly the geography, geology, water in bedrock, and in unconsolidated deposits, artesian conditions, springs, and quality of water. Gives detailed information regarding water supplies in the Las Vegas drainage basin, Duck, Ursine, and Meadow valleys, White River drainage basin, Muddy and Virgin valleys, and Bristol, Delamar, Coal, Garden, Dry Lake, Indian Spring, and Railroad valleys. Contains water analyses, a guide to watering places on routes of travel, and a table of distances between watering places. Includes maps showing Pleistocene lake beds, areas of artesian flow, and locations of watering places.

370. (See p. 49-50.)

373. Water resources of Hawaii, 1913, by G. K. Larrison. 1915. 190 pp. 20c.

Relates chiefly to surface waters, but contains data on the discharge of springs, tunnels, and flowing wells on the island of Oahu (p. 103), springs on the island of Maui (p. 151), and springs on the island of Hawaii (p. 174).

374. Ground water in the Hartford, Stamford, Salisbury, Willimantic, and Saybrook areas, Conn., by H. E. Gregory and A. J. Ellis. 1916. 150 pp., 13 pls. 30c.

Covers the towns of Bloomfield, Canaan, East Hartford, East Windsor, Essex, Franklin, Greenwich, Hartford, Manchester, Newington, North Canaan, Old Lyme, Salisbury, Saybrook, Stamford, South Windsor, Westbrook, West Hartford, Wethersfield, Windham, and Windsor. Discusses the origin, circulation, quantity, and quality of the waters in stratified and unstratified drift, crystalline rocks, traps, Paleozoic limestones, and Triassic sandstones. Discusses ground water for municipal use and the construction of drilled, driven, and dug wells, and infiltration galleries. Describes the municipal pumping plants at Brookline, Mass., Brooklyn, N. Y., and Plainfield, N. J. Describes the ground water conditions in detail, by towns. Contains numerous tables of well data and water analyses, and includes maps showing water-bearing formation, depths to water, locations of wells, and woodlands.

*375. Contributions to the hydrology of the United States, 1915; N. C. Grover, chief hydraulic engineer. 1916. 181 pp., 9 pls. 15c.

Issued also in separate chapters. The following chapters relate to ground water:

(*a*) Ground water for irrigation in the Sacramento Valley, Cal., by Kirk Bryan (pp. 1-49. Pls. I-II).

(*b*) Ground water in Paradise Valley, Ariz., by O. E. Meinzer and A. J. Ellis (pp. 51-75, Pls. III-V).

(*d*) Ground water in Big Smoky Valley, Nev., by O. E. Meinzer (pp. 85-116, Pls. VI-VII).

(*g*) Ground water in Lasalle and McMullen counties, Tex., by Alexander Deussen and R. B. Dole (pp. 141-177, Pls. VIII-IX).

All of these papers include maps showing ground-water conditions. No. 375-A contains statistics on irrigation with ground water in Sacramento Valley and a discussion of problems relating to the construction of wells and to pumping for irrigation. No. 375-D contains data on ground-water intake and discharge and on irrigation with ground water. No. 375-G discusses water in the various geologic formations, especially with reference to its quality and quantity for irrigation; it contains tables of well data and water analyses.

380. The Navajo country—a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah, by H. E. Gregory. 1916. 219 pp., 29 pls. 80c.

Covers the Navajo and Hopi Indian reservations, in northeastern Arizona, northwestern New Mexico, and southeastern Utah, and some adjacent areas. Gives an outline of the history of the region; describes the geographic provinces, climate, soil, flora, fauna, and geology; describes also the streams and discusses factors influencing stream flow, irrigation with surface waters, storage of rain and surface waters for domestic and stock use, and water powers; discusses ground-water reservoirs, quality of ground water, artesian water, springs, and wells; gives data on watering places and recommendations for prospecting for water in various geographic provinces. Includes maps showing the geology, the locations of watering places, roads, and trails, and the areas covered by forests.

389. (See p. 50.)

390. (See p. 50.)

393. (See p. 50.)

394. (See p. 50.)

*397. Ground water in the Waterbury area, Conn., by A. J. Ellis, under the direction of H. E. Gregory. 1916. 73 pp., 4 pls. 15c.

Discusses the water in glacial drift and crystalline rocks, ground water for private and municipal uses, and methods of developing ground-water supplies. Describes the municipal pumping plants at Brookline, Mass., Brooklyn, N. Y., and Plainfield, N. J. Describes in detail the water-bearing formations and water supplies in the towns of Ansonia, Beacon Falls, Middlebury, Naugatuck, Oxford, Seymour, Thomaston, Waterbury, and Watertown. Contains tables of well data and water analyses, and includes a map showing areas underlain by stratified drift, rock outcrops, woodlands, and locations of wells and springs.

398. Ground water in San Joaquin Valley, Cal., by W. C. Mendenhall, R. B. Dole, and Herman Stabler. 1916. 310 pp., 5 pls. 25c.

Describes the development of irrigation in the Southwest and gives an outline of the geography and geology of the San Joaquin basin. Discusses briefly the origin, circulation, quantity, and availability of ground water, and its use for irrigation. Describes the quality of the surface and ground waters, the standards for classification, the methods of purifying water, and the effects of quality on use. Explains the variations in the quality of the water with its depth below the surface and with its geographic and geologic relations. Gives details of 55 pumping tests and summarizes and discusses the results. Gives numerous well records and water analyses and detailed descriptions by counties. Includes maps showing areas of artesian flow, contours of the water table, quality of ground water, and locations of the pumping plants investigated.

399. Geology and ground waters of northeastern Arkansas, by L. W. Stephenson and A. F. Crider, with a discussion of the chemical character of the waters, by R. B. Dole. 1916. 315 pp., 11 pls. 35c.

Covers an area of about 13,250 square miles extending from Mississippi River west to the Ozark province and from Missouri south to Arkansas River. Describes the physiography, geology, surface waters, stratigraphic distribution of ground waters, springs, artesian waters, and uses of ground water, especially in irrigating rice. Gives detailed descriptions, well sections, and tables of well data by counties. Discusses chemical standards of classification, methods of purification, and the quality of the waters in relation to the strata in which they occur, their geographic positions, and their depths below the surface. Includes numerous analyses and maps showing the geology, the areas of artesian flow, and the locations and depths of wells.

*400. Contributions to the hydrology of the United States, 1916; N. C. Grover, chief hydraulic engineer. 1917. 108 pp., 7 pls.

Issued also in separate chapters. The following chapters relate to ground water:

(*b*) Artesian water for irrigation in Little Bitterroot Valley, Mont., by O. E. Meinzer (pp. 9-37, Pls. I-IV).

(*e*) Ground water for irrigation in the Morgan Hill area, Cal., by W. O. Clark (pp. 61-106, Pls. V-VII).

Both papers include maps showing ground-water conditions. No. 400-E contains numerous well sections and records of water levels in wells and an estimate of the annual ground-water supply, based chiefly on fluctuations of the water table and porosity of the water-bearing deposits.

416. The divining rod, a history of water witching, with a bibliography, by A. J. Ellis. 1917. 55 pp.

Gives an outline of the history of the popular delusion known as "water witching" and points out fallacies in so-called "mechanical water finders." Advises the public against expending money "for the services of any water witch or for the use or purchase of any machine or instrument devised for locating underground water or other minerals." Lists numerous papers on the subject from 1532 to the present time.

418. Mineral springs of Alaska, by G. A. Waring, with a chapter on the chemical character of some surface waters of Alaska, by R. B. Dole and A. A. Chambers 1917. 114 pp., 9 pls.

Describes hot springs in 48 localities, carbonated springs in 12 localities, and sulphur springs in 13 localities, also iron springs and salt springs. Discusses the chemical character of the waters of Yukon, Tanana, Lowe, Copper, Stikine, and other rivers. Contains 32 analyses of spring waters and 38 analyses of surface waters. Includes a map of Alaska showing the locations of 108 groups of mineral springs in relation to volcanoes.

422. Ground water in Animas, Playas, Hachita, and San Luis basins, N. Mex., by A. T. Schwennesen (in press).

Covers the southern part of Grant County. Describes the physiography and geology and the ground-water conditions in each basin with respect to the occurrence, depth, quantity, quality, artesian conditions, and irrigation prospects. Gives well data, analyses of water, and analyses of the water-soluble contents of the soil. Contains a map of the area showing depths to the water table and other features.

423. Geology and water resources of Big Smoky, Clayton, and Alkali Spring valleys, Nev., by O. E. Meinzer. 1917. 167 pp., 15 pls.

Describes the physiography and geology with special reference to Quaternary events; gives data on precipitation, stream flow, seepage, springs, and wells; estimates intake and discharge of ground water; discusses criteria for recognizing shallow-water areas; discusses the quality of the water with reference to the geologic source of the valley fill, geographic provinces, and use describes public water supplies and discusses irrigation with ground water; contains analyses of water and of alkali in soil; includes maps showing Pleistocene lake features, depths to ground water, areas of ground water intake and discharge, and locations of watering places.

425. Contributions to the hydrology of the United States, 1917; N. C. Grover, chief hydraulic engineer. 1918.

Issued also in separate chapters. The following papers relate to ground water:

(*a*) Ground water in San Simon Valley, Ariz., by A. T. Schwennesen, with a chapter on agriculture by R. H. Forbes (pp. 1–35, Pls. I–III). Describes the physiography and geology of the valley, the upper water horizon, and the deeper artesian horizon of the San Simon and Bowie areas, the ground water in the Rodeo and Artesia valleys, and the irrigation supplies from flowing and nonflowing wells; contains 39 analyses of well and spring waters, numerous records of deep wells and maps showing areas of artesian flow, depth to water table, and lands irrigated with well water; also includes a chapter by R. H. Forbes on soil, vegetation, and agricultural prospects.

(*b*) Ground water for irrigation in Lodgepole Valley, Wyo.-Nebr., by O. E. Meinzer (pp. 37–69 Pls. IV–VI). Describes the physiography and geology of Lodgepole Valley and the adjacent region and the water in the alluvial gravel and in the Tertiary and Cretaceous formations; discusses irrigation with ground water; gives well data and analyses of 20 well waters and 2 samples from Lodgepole Creek; contains maps showing the geology and the depths to the water table; also includes data on the cost of pumping for irrigation in western Nebraska, by H. C. Diesem, U. S. Department of Agriculture.

(*d*) Ground water in Reese River valley and adjacent parts of Humboldt River valley, Nev., by G. A. Waring (pp. 95–129, Pls., VII–XII). Describes the physiography, geology, ground-water conditions, and irrigation prospects. Contains well and spring data and analyses of ground waters. Includes a map showing the geology, shallow-water areas, and areas of artesian flow.

(*e*) Ground water in Quincy Valley, Wash., by A. T. Schwennesen and O. E. Meinzer (pp. 131–158, Pl. XIII–XIV). A preliminary report which outlines the physiographic features, climate, and agricultural conditions of Quincy Valley and adjacent regions; describes the character and distribution of the Yakima basalt, Pleistocene lake beds, and Pleistocene outwash gravels, and discusses quantity, quality, and head of water in each of these formations; discusses present and prospective irrigation with ground water. Contains a sketch map showing contours of the water table.

428. Artesian water in the vicinity of the Black Hills, S. Dak., by N. H. Darton (in press).

Describes the geology and artesian-water conditions in areas covered in previous reports but in the light of additional data. Discusses the artesian prospects of the Dakota, Minnelusa, and Deadwood sandstones. Contains a map showing the geology and the depths to the water-bearing sandstones.

430. Surface water supply of Hawaii, July 1, 1913, to June 30, 1915; N. C. Grover, chief hydraulic engineer; G. K. Larrison, district engineer. 1917. 329 pp.

Contains data on the discharge of springs, tunnels, and flowing wells on the Island of Oahu (pp. 205–207).

445. Surface water supply of Hawaii, July 1, 1915, to June 30, 1916; N. C. Grover, chief hydraulic engineer; G. K. Larrison, district engineer. 1917. 224 pp.

Contains discharge records for springs near Kailua, Oahu (pp. 97–99), and for Kahoma development tunnel, near Lahaina, Maui (pp. 156, 157).

## ANNUAL REPORTS.

*Fifth Annual Report (1883–84). 1885. 469 pp., 58 pls. $2.25.

The following paper relates to ground water:

*(A 5 c) The requisite and qualifying conditions of artesian wells, by T. C. Chamberlin (pp. 125 to 173, Pl. XXI). This is the first paper published by the United States Geological Survey on the subject of ground water. It is a clear, accurate, and comprehensive statement of the conditions that produce artesian basins and give rise to flowing wells, and is regarded as authoritative on the subject.

*Ninth Annual Report (1887–88). 1889. 717 pp., 88 pls. $2.

The following paper relates to ground water:

*(A 9 d) Formation of travertine and siliceous sinter by the vegetation of hot springs, by W. H. Weed (pp. 613–676, Pls. LXXVIII–LXXXVII). Describes the Mammoth Hot Springs and other hot springs and geysers of Yellowstone National Park, also hot springs in New Zealand; gives analyses and discusses the chemical character of the waters from these springs and the deposits which they form.

Eleventh Annual Report (1899–90). Part II. Irrigation. 1891. 395 pp., 30 pls. and maps. $1.25.

*(A 11 II c) Includes a section on artesian irrigation on the Great Plains (pp. 260–278), in which the limitations imposed by quantity, head, and cost are discussed, and irrigation by means of artesian wells in various countries is described. Records are given of wells in Kansas, Minnesota, Montana, Nebraska, North Dakota, South Dakota, and Texas.

Thirteenth Annual Report (1891–92). Part III. Irrigation. 1893. 486 pp., 77 pls. $1.85.

The following papers relate in part to ground water:

*(A 13 III a) Water supply for irrigation, by F. H. Newell (pp. 7-99, Pls. CVIII–CX). Includes a brief discussion on "subsurface waters" (pp. 28-30), giving statistics on artesian wells and irrigation with well water in the United States in 1890, and commenting accurately on quantity, occurrence, and discharge of water in desert valleys.

*(A 13 III b) American irrigation engineering, by H. M. Wilson (pp. 100-349, Pls. CXI–CXLVI). Includes a chapter on subsurface or ground waters with special reference to irrigation (pp. 326-346), in which are discussed artesian and pumped wells, underflow dams, infiltration galleries, and subirrigation.

Fourteenth Annual Report (1892–93). *Part II. Accompanying papers. 1893. 597 pp., 73 pls. $2.10.

The following papers relate to ground water:

*(A 14 II a) Potable waters of the eastern United States, by W J McGee (pp. 1 to 47). Discusses cistern water, stream waters, and ground waters, including mineral springs and artesian wells.

*(A 14 II b) Natural mineral waters of the United States, by A. C. Peale (pp. 49-88, Pls. III and IV). Discusses the history, origin, flow, classification, and geographic distribution of mineral and thermal springs, the chemical composition and analysis of spring waters, and the utilization of mineral waters. Gives a list of American mineral spring resorts.

Sixteenth Annual Report (1894–95). *Part II. Papers of an economic character. 1895. 598 pp., 43 pls. $1.25.

The following papers relate in part to ground water:

*(A 16 II e) The public lands and their water supply, by F. H. Newell (pp. 457-533, Pls. XXXV–XXXIX). Describes the public lands and the streams, wells, and reservoirs as sources of water supply; contains a brief but comprehensive and farsighted discussion of the ground-water resources of the West (pp. 499-502); includes brief notes on ground water in Arizona, California, Colorado, Idaho, Kansas, Nebraska, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, and Washington (pp. 504-533).

(A 16 II f) Water resources of a portion of the Great Plains, by Robert Hay (pp. 535-588, Pls. XL–XLII). Describes an indefinite area that lies on both sides of the east boundary of Colorado and extends from the vicinity of Smoky Hill River northward to the North Platte, thus comprising parts of Colorado, Nebraska, and Kansas. Discusses the lakes, streams, and springs of the area, the underflow of the river bottoms, and the water-bearing strata beneath the higher lands, the source, quantity, and rate of percolation of ground water, the wells in the valleys and on the uplands, the unsuccessful wells, artesian conditions, "blowing" wells and the temperatures of the well waters. Describes briefly the topography and geology of the region and the utilization of the water supply.

Seventeenth Annual Report (1895–96). *Part II. Economic geology and hydrography. 1896. 864 pp., 113 pls. $2.35.

The following papers relate to ground water:

(A 17 II f) The underground water of the Arkansas Valley in eastern Colorado, by G. K. Gilbert (pp. 551-601, Pls. LVI–LXVIII). Relates to an indefinite region adjacent to Arkansas River, in southeastern Colorado. Describes the topography, geology, artesian conditions, and intake areas of the region, the water in the Dakota sandstone, in the upland sands, beneath the terraces, and in the dune sands, and the underflow of rivers and creeks. Includes a sketch map showing the depths to artesian water. See also Professional Paper 52.

(A 17 II g) Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton (pp. 603-694, Pls. LXIX–CVII). Covers the part of South Dakota lying east of the 101st meridian and the part of North Dakota lying east of the 101st meridian and south of the 47th parallel. Gives an outline of the geologic relations, describes the water horizons and the extent of the artesian waters, gives detailed information by counties concerning wells and prospects for obtaining wells, discusses the origin, quantity, head, and quality of the artesian waters and their use for developing power, gives data by counties regarding irrigation with artesian water and directions as to the construction and management of artesian wells. Includes maps showing the areas of artesian flow supplied from the Dakota sandstone and from glacial drift, respectively, the height to which the artesian water will rise, the depths to principal artesian horizon of the Dakota sandstone, and contours of the surface of the bedrock.

*(A 17 II h) The water resources of Illinois, by Frank Leverett (pp. 695-849, Pls. CVIII–CXIII). Describes the topography, drainage, precipitation, run-off, navigable rivers, water powers, wells supplying water for cities, villages, and rural districts, wells in alluvium, glacial drift, and Tertiary and Paleozoic formations, and flowing wells. Contains tabulated well data and water analyses, and includes maps of Illinois and eastern Indiana showing the distribution of Pleistocene deposits, the relation of glacial drift to ground-water supplies, the elevation of the St. Peter sandstone, and areas in which there are flowing wells supplied by glacial drift. Also contains a map of Wisconsin and northern Illinois showing the main intake areas of the "Potsdam" and St. Peter sandstones.

Eighteenth Annual Report (1896–97). *Part II. Papers chiefly of a theoretic nature. 1897. 653 pp., 105 pls. $1.65.

The following paper relates to ground water:

*(A 18 II b) Geology of portions of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex., with special reference to the occurrence of artesian and other underground waters, by R. T. Hill and T. W. Vaughan (pp. 193–322, Pls. XXI–LXIV.) Describes the geography, geology, water-bearing formations, springs, and flowing and nonflowing wells. Discusses the artesian conditions, the probable identity of source of artesian and fissure-spring waters, and the quality of the artesian water. Contains water analyses and includes a map of the vicinity of Austin showing the relations of the springs and artesian wells to the geology.

Eighteenth Annual Report (1896–97). *Part IV. Hydrography. 1897. 756 pp., 102 pls. $1.75.

The following papers relate to ground water:

*(A 18 IV b) The water resources of Indiana and Ohio, by Frank Leverett (pp. 419–560, Pls. XXXIII–XXXVII). Describes the drainage systems, the ground-water conditions, the flowing and nonflowing wells in glacial drift and rock formations, and the mineral springs. Contains numerous well records and water analyses. Gives data regarding water supplies for cities and villages derived from surface and underground sources. Includes maps of Indiana and Ohio showing the Pleistocene deposits, the older geologic formations, and the relation of ground-water supplies to the depth of the glacial drift.

*(A 18 IV c) New development in well boring and irrigation in eastern South Dakota, by N. H. Darton (pp. 561–616, Pls. XXXVIII–XLVII). Describes the progress that was made in 1896 in drilling wells and in irrigating with artesian waters in Aurora, Beadle, Bonhomme, Brule, Buffalo, Charles Mix, Davison, Douglas, Hanson, Hutchinson, Jerauld, Sanborn, Spink, and Yankton counties, and in areas west of Missouri River. Discusses the temperature, pressure, and flow of the artesian waters, the extent of the artesian basin, and the position of the bedrock. Gives analyses of waters from Missouri River and from artesian wells in the Sanborn basin. Includes maps showing the rate of increase of temperature in wells with depth, contours of the bedrock surface, and flow of wells.

Nineteenth Annual Report (1897–98). *Part II. Papers chiefly of a theoretic nature. 1899. 958 pp., 172 pls. $2.65.

The following papers relate to ground water:

*(A 19 II b) Principles and conditions of the movements of ground water, by F. H. King (pp. 59–294, Pls. VI–XVII). Discusses the quantity of water stored in soil, in sandstone, and in other rocks, the depth to which ground water penetrates, the gravitational, thermal, and capillary movements of ground water, and the configuration of the water table. Gives the results of tests made by the author and by earlier investigators of the flow of air and water through rigid, porous media and through sands, sandstones, and silts. Summarizes these results and draws conclusions regarding the relation of velocity to pressure. Discusses also the influence of form, diameter, and arrangement of sand grains on velocity, the methods of determining diameters of sand grains, the growth of rivers, the rate of seepage into filtration ditches, the interference of wells, and related subjects.

*(A 19 II c) Theoretical investigation of the motion of ground waters, by C. S. Slichter (pp. 295–384, Pl. XVII). A mathematical discussion of the laws governing the movements of ground water, the discharge of flowing wells, and the mutual interference of wells. Includes a bibliography on the motion of ground waters and related topics.

Nineteenth Annual Report (1897–98). *Part IV. Hydrography. 1898. 814 pp., 118 pls. $1.85.

The following papers relate to ground water:

*(A 19 IV b) The rock waters of Ohio, by Edward Orton (pp. 633–717, Pls. LXXI–LXXIII.) Describes the principal geologic formations of Ohio and the waters which they yield; gives detailed information regarding the water supplies of many cities and villages; discusses the flowing wells in various localities, including those in the preglacial channels of Allen, Auglaize, and Mercer counties; and includes a number of water analyses.

*(A 19 IV c) Preliminary report on the geology and water resources of Nebraska west of the 103d meridian, by N. H. Darton (pp. 727–785, Pls. LXXIV–CXVIII). Describes the general geology of Nebraska, and the topography, geology, and water horizons of the area covered by the reports. Gives information on springs, streams, irrigation, climate, and timber, and of elevations of various points. Includes a general geologic map of Nebraska and more detailed maps of the portion of the State west of the 103d meridian, showing the geology and the ground-water conditions. Reprinted as Professional Paper 17.

Twenty-first Annual Report (1899–1900). *Part IV. Hydrography. 1901. 768 pp., 156 pls. $2.35.

The following papers relate in part to ground water:

*(A 21 IV a) Report of progress of stream measurements for the calendar year 1899, by F. H. Newell (pp. 9–488, Pls. I–LVII). Includes brief notes on ground-water supplies at Kearney, Nebr. (pp. 216–217), Alamosa, Colo. (p. 265 and Pl. IV, *A*), San Pedro Valley, Ariz. (pp. 352–353 and Pl. XXXI, *A*), Mohave Valley, Cal. (p. 472, and Pl. LII), Los Angeles River valley, Cal. (p. 474), Lytle Creek valley, Cal. (pp. 481–482), and Mission Valley, Cal. (p. 486). The plates referred to are photographs of flowing wells or other ground-water features.

*(A 21 IV b) Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming, by N. H. Darton (pp. 489–599, Pls. LVIII–CXII). Covers an area comprising about 5,500 square miles in southwestern South Dakota and the adjoining portion of Wyoming. Describes the topography, geology, water horizons, wells, surface waters, irrigation, soil, mineral resources, climate, and timber of the area. Includes maps showing the geology, the depths to the Dakota sandstone, and other ground-water conditions.

*(A 21 IV c) The High Plains and their utilization, by W. D. Johnson (pp. 601–741, Pls. CXIII–CLVI). Describes the area lying in an irregular belt about midway across the long eastward slope of the Great Plains and including parts of Wyoming, Nebraska, Colorado, Kansas, New Mexico, and Texas. Gives a comprehensive description of the physiographic features and Tertiary deposits of the region and a critical discussion of their interpretation. Discusses precipitation, climate, and the use of streams and storm waters for irrigation. Describes the artesian conditions, with special reference to the Meade artesian basin, and explains the principles of artesian and other ground waters. Concluded in the Twenty-second Annual Report, Pt. IV.

Twenty-first Annual Report (1899–1900). *Part VII. Geography and geology of the Black and Grand prairies, Tex., with detailed descriptions of the Cretaceous formations and special reference to artesian waters, by R. T. Hill. 1901. 666 pp., 71 pls. $1.90.

Gives a general description of the geography of a region including Texas, Oklahoma, and New Mexico east of the Rio Grande, and describes in more detail the geography and geology of the Black and Grand prairies. Discusses the principles governing artesian and other ground waters, the artesian systems of Texas, and the quality of the waters of these systems. Describes the artesian conditions by counties and gives analyses. Includes maps showing the geology, the locations of artesian wells, and the outcrop of, depths to, and areas of artesian flow from the Trinity, Paluxy, and Woodbine formations.

Twenty-second Annual Report (1900–1901). Part IV. Hydrography. 1902. 690 pp., 65 pls. $2.20.

The following paper relates to ground water:

*(A 22 IV c). The High Plains and their utilization, by W. D. Johnson (pp. 631–669, Pls. LI–LXV). This is the concluding part of the paper on the High Plains and their utilization begun in the Twenty-first Annual Report, Part IV. It discusses the occurrence of water, consolidated and unconsolidated formations, the origin and level of the ground water of the High Plains, the utilization of ground water for stock raising and irrigation, and methods of constructing wells.

## MONOGRAPHS.

25. The glacial Lake Agassiz, by Warren Upham. 1896. 658 pp., 38 pls. $1.70.

Contains a chapter (pp. 523–582) on "Artesian and common wells of the Red River Valley," which discusses the sources of artesian water, the fresh waters in the drift sheets, the saline and alkaline waters in the Dakota sandstone, and the use of artesian water for irrigation; contains analyses of waters from wells, streams, and lakes in Red River Valley and the adjoining region; and gives notes on wells in Clay, Kittson, Marshall, Norman, Polk, Traverse, and Wilkin counties, in Minnesota: in Cass, Grand Forks, Pembina, Richland, Traill, and Walsh counties, in North Dakota; and in a part of the area covered by Lake Agassiz, in Manitoba. The monograph includes numerous maps relating to the Pleistocene geology of the region and a map (Pl. XXXVII) showing the distribution and depths of artesian wells in glacial drift and bedrock.

27. Geology of the Denver Basin in Colorado, by S. F. Emmons, Whitman Cross, and G. H. Eldridge. 1896. 556 pp., 31 pls. $1.50.

Contains a discussion of the water in the Pleistocene deposits (pp. 272, 273) and a section on artesian wells (pp. 401-465). Discusses the history of artesian-water developments in Colorado, the water-bearing horizons, the artesian structure, the quantity of artesian water, and the yield and decrease in yield of flowing wells. Includes three analyses of well waters and maps showing the geology of the region and the original area of artesian flow.

38. The Illinois glacial lobe, by Frank Leverett. 1899. 817 pp., 24 pls. $1.60.

Includes a chapter (pp. 550-788) on "Wells of Illinois," which contains a general discussion of artesian and other wells, a table of municipal water supplies derived from underground sources, and a detailed description of wells and ground-water conditions in practically every county in the State. The monograph includes maps showing the geology, the distribution of wells, the intake areas of "Potsdam" and St. Peter sandstones, and the relation of glacial drift to ground-water supplies.

*47. A treatise on metamorphism, by C. R. Van Hise. 1904. 1286 pp., 13 pls.

This comprehensive treatise deals in much detail with the chemical and physical laws governing ground water, especially in the following sections: "Chemical and physical principles controlling the action of ground water" (pp. 65-123), "Circulation and work of ground water" (pp. 123-158), "The belt of weathering" (pp. 411-429), "The belt of cementation" (pp. 560-594), and "Work of aqueous solutions in segregating ores" (pp. 1072-1198).

## PROFESSIONAL PAPERS.

*17. Preliminary report on the geology and water resources of Nebraska west of the 103d meridian, by N. H. Darton. 1903. 69 pp., 43 pls. 25c.

Reprint of a paper in the Nineteenth Annual Report, Part IV, with slight changes.

*32. Preliminary report on the geology and underground-water resources of the central Great Plains, by N. H. Darton. 1905. 433 pp., 72 pls. $1.80.

Covers South Dakota, Nebraska, central and western Kansas, eastern Colorado, and eastern Wyoming. Describes the geography, geology, and water horizons; gives deep-well data and well prospects by counties; also describes other mineral resources. Includes maps showing the geology, locations of deep wells, structure of the Dakota sandstone, depths to this sandstone, head of artesian water, and areas of artesian flow.

*44. Underground-water resources of Long Island, N. Y., by A. C. Veatch, C. S. Slichter, Isaiah Bowman, W. O. Crosby, and R. E. Horton. 1906. 394 pp., 34 pls. $1.25.

Describes the geologic formations, the source and occurrence of ground water, and the conditions necessary to obtain flowing wells; gives data in regard to the springs, streams, ponds, lakes, artesian and other deep wells, the water table and its fluctuations, blowing wells, and waterworks; contains records of the rate of movement of the ground water and results of sizing and filtration tests; gives well records and notes concerning representative wells. Includes water analyses and maps showing the geology, contours of the water table, and locations of wells and waterworks.

*46. Geology and underground-water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. 422 pp., 51 pls. $1.50.

Covers Louisiana north of the 31st parallel, about the southern half of Arkansas, and adjacent areas in Texas, Oklahoma, and Mississippi. Describes the physiography and geology of the region, the principles governing ground waters and their application to this region, the water-bearing formations with reference to springs and to the artesian pressure, quality, and availability of the water, the occurrence of mineral waters, the hygienic value of deep-well waters, and methods and costs of constructing wells. Contains a description of the ground-water conditions in each county and tables of well data arranged by counties, with notes giving well sections and water analyses. Contains also a dictionary of altitudes, arranged by counties. Includes maps showing the geology of the region, the structure contours of the Nacatoch and Bingen formations, areas of artesian flow supplied by these formations, depths to the Sabine and Cockfield sands, and areas of artesian flow supplied by these sands.

*51. Geology of the Bighorn Mountains, by N. H. Darton. 1906. 129 pp., 47 pls.

Describes the geology of the region in detail and contains a brief discussion (pp. 119 and 120) of the probable depths and water-bearing conditions of the principal sandstones. Includes a geologic map.

*52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.

Describes the geology of the greater part of the drainage basin of Arkansas River in Colorado, the source, depths, head, areas of artesian flow, quantity, and quality of the water in the Dakota sandstone, and the occurrence and quality of the waters in the Red Beds, Morrison formation, Laramie and associated formations, later Tertiary deposits, and dune sands. Includes numerous well sections, several water analyses, and maps showing the geology, depths to Dakota sandstone, areas of artesian flow, and areas not underlain by Dakota sandstone. A preliminary report on the same region, by G. K. Gilbert, was published in the Seventeenth Annual Report, part 2, 1896, pp. 1-51.

*53. Geology and water resources of the Bighorn Basin, Wyo., by C. A. Fisher. 1907. 72 pp., 16 pls.

Describes the geography, geology, water-bearing formations, irrigation developments, mineral waters, and other mineral resources of the basin. Includes a geologic map.

*56. Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil, by A. C. Veatch. 1907. 178 pp., 26 pls. 60c.

Covers the southwest corner of Wyoming and a small adjacent portion of Utah. Gives a detailed description of the geology and a brief discussion of the water-bearing formations. Includes a geologic map with structure contours.

*65. Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming, by N. H. Darton. 1909. 105 pp., 24 pls. 40c.

Describes the geology of the sedimentary rocks and discusses their mineral resources, including their water supplies. Contains also information concerning the timber, climate, and surface waters available for irrigation and stock raising. Includes maps showing the geology, outcrops of and depths to principal water-bearing formations, and areas of artesian flow.

*90. Shorter contributions to general geology, 1914; David White, chief geologist. 1915. 199 pp., 21 pls. 40c.

Issued also in separate chapters. The following paper relates in part to ground water:

(*h*) A deep well at Charleston, S. C., by L. W. Stephenson, with a report on the mineralogy of the water, by Chase Palmer (pp. 69-94).

94. Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder counties, Colo., by E. S. Bastin and J. M. Hill. 1917. 379 pp., 23 pls.

Discusses, on pages 134 to 152, the relation of ground water to ore deposition, especially the relation of the water table to the downward enrichment of gold, silver, and copper ores. Contains, however, almost no data regarding ground water.

95. Shorter contributions to general geology, 1915; David White, chief geologist. 1916. 120 pp., 7 pls. 20c.

Issued also in separate chapters. The following paper relates in part to ground water:

*(*a*) The composition of muds from Columbus Marsh, Nev., by W. B. Hicks (pp. 1-11). Gives data in regard to shallow wells on Columbus Marsh.

## BULLETINS.

*32. Lists and analyses of the mineral springs of the United States (a preliminary study), by A. C. Peale. 1886. 235 pp.

Defines mineral waters, gives lists of springs by States, and contains 819 analyses of spring waters.

*47. Analyses of waters of the Yellowstone National Park, with an account of the methods of analysis employed, by F. A. Gooch and J. E. Whitfield. 1888. 84 pp.

Describes methods used in analyzing natural waters and contains analyses of 43 geyser, spring, and surface waters in Yellowstone National Park.

*108. A geological reconnaissance in central Washington, by I. C. Russell. 1893. 108 pp., 12 pls. 15c.

Describes the main geologic features of a region lying approximately between the 119th and 121st meridians and between the 46th and 48th parallels. Gives conclusions regarding prospects for artesian wells and includes a sketch geologic map. This bulletin is largely superseded by Water-Supply Papers 55, 118, and 316.

*131. Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell. 1895. 126 pp. 15c.

Gives the discharge of Barton Spring, near Austin, Tex., as 17 second-feet on November 13, 1894 (p. 92). Contains records of wells collected by Robert Hay in Nebraska, Colorado, and Kansas (pp. 92–126).

*138. Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton. 1896. 232 pp., 19 pls.

Describes briefly the geologic structure and the ground-water conditions in the Atlantic Coastal Plain. Covers the Coastal Plain areas of New York, New Jersey, Delaware, Maryland, District of Columbia, Virginia, North Carolina, South Carolina, and eastern Georgia, giving for each of these States a discussion of the geologic relations and well prospects, tabulated data regarding deep wells, and notes giving well sections, water analyses, and other detailed information not found in the tables. Includes maps and sections showing ground-water conditions.

*140. Report of progress of the division of hydrography for 1895, by F. H. Newell. 1896. 356 pp. 25c.

Gives descriptions and discharge records for the following springs in Texas: San Marcos Spring, San Antonio and San Pedro springs, Las Moras Spring, San Felipe Springs, and Barton Springs (pp. 83–86). Contains data on seepage and evaporation in Nebraska and Kansas (pp. 347–350).

*164. Reconnaissance in the Rio Grande coal fields of Texas, by T. W. Vaughan. 1900. 100 pp., 11 pls. 20c.

Contains brief notes on artesian wells in the vicinities of Eagle Pass and Carrizo springs. See especially pp. 25, 50–52.

*199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls. 25c.

Gives a general sketch of the geography and geology of an indefinite region in Idaho adjacent to Snake River. Discusses artesian and other ground-water conditions and includes a meager amount of well data.

*227. The United States Geological Survey, its origin, development, organization, and operations. 1904. 205 pp., 9 pls. 25c.

Includes a brief account (pp. 84–88) of the Division of Hydrology (ground water) and of the investigations relating to ground water made by the United States Geological Survey prior to 1904.

*238. Economic geology of the Iola quadrangle, Kans., by G. I. Adams, Erasmus Haworth, and W. R. Crane. 1904. 83 pp., 11 pls. 25c.

Describes the geology and contains a geologic map of the quadrangle. Discusses briefly the water-bearing formations and the quality of their waters (p. 77).

252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls. 15c.

Covers an indefinite region that lies partly in the Great Basin and partly in the basin of Deschutes River, and includes portions of Malheur, Harney, and Crook counties. Describes the geography and geology of the region, gives meager data regarding the surface and ground waters, discusses briefly the artesian conditions in the Deschutes basin, and makes suggestion concerning records of artesian wells.

*264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp. 10c.

Discusses the importance of accurate well records to drillers, to owners of oil, gas, and water wells, and to geologists. Describes methods of work. Gives tabulated records of wells in 39 States and Territories, and detailed records of wells in California, Colorado, Illinois, Iowa, Kansas, Mississippi, Missouri, New Jersey, New York, Ohio, Pennsylvania, Texas, and West Virginia.

265. Geology of the Boulder district, Colo., by N. M. Fenneman. 1905. 101 pp., 5 pls. 15c.

Describes the geology of a rectangular area 16 miles north and south by 9 miles east and west, in the southwestern part of which is situated the city of Boulder. Discusses briefly (pp. 67–69) the flowing wells and water-bearing formations, including the Dakota sandstone. Contains a geologic map of the area.

*282. Oil fields of the Texas-Louisiana Gulf Coastal Plain, by N. M. Fenneman. 1906. 146 pp., 11 pls.

Includes well records and discussions of phenomena related to wells, drilling methods, and movements, temperatures, and salinity of ground waters.

*285. Contributions to economic geology, 1905; S. F. Emmons and E. C. Eckel, geologists in charge. 1906. 506 pp., 13 pls.

Issued also in separate chapters. The following paper contains information on ground water: *(*f*) Coal and oil in southern Uinta County, Wyo., by A. C. Veatch (pp. 331–353, Pls. X–XII). Describes the geology of an area that occupies Tps. 12 to 23 N., Rs. 115 to 121 W., inclusive, in Uinta County, Wyo. Contains a geologic map and a brief statement in regard to artesian conditions and prospects (p. 353). This area is covered more fully in Professional Paper 56.

*298. Record of deep-well drilling for 1905, by M. L. Fuller and Samuel Sanford. 1906. 299 pp. 25c.

Gives an account of progress in the collection of well records and samples. Contains tabulated records of wells in 48 States and Territories and detailed records of wells in Alabama, Arizona, Arkansas, California, Colorado, Delaware, Florida, Georgia, Illinois, Indiana, Indian Territory, Iowa, Kansas, Kentucky, Maine, Maryland, Massachusetts, Minnesota, Mississippi, Missouri, Montana, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, South Dakota, Texas, Utah, Washington, West Virginia, and Wisconsin.

*300. Economic geology of the Amity quadrangle, eastern Washington County, Pa., by F. G. Clapp. 1907. 145 pp., 8 pls. 30c.

Contains a description of the geology of the quadrangle and a map showing outcrops and structure. Includes brief statements on water supplies and water-bearing formations (pp. 130–134). The quadrangle is covered more fully in Geologic Folio 144, which also contains information on ground water.

*308. A geologic reconnaissance in southwestern Nevada and eastern California, by S. H. Ball. 1907. 218 pp., 3 pls. 40c.

Contains a brief section on "Hydrology," which discusses streams, springs, tanks, wells, and signs of water (pp. 18–23). Contains descriptions of specific areas which give detailed information regarding springs, wells, and other watering places. Includes a geologic map that also shows watering places and connecting roads.

*319. Summary of the controlling factors of artesian flows, by Myron L. Fuller. 1908. 44 pp., 7 pls. 10c.

Describes underground reservoirs, the sources of ground water, the confining agents, the primary and modifying factors of artesian circulation, the essential and modifying factors of artesian flow, and typical artesian systems.

*330. The data of geochemistry, by F. W. Clarke. 1908. 716 pp.

Superseded by Bulletin 616.

*350. Geology of the Rangely oil district, Rio Blanco County, Colo., with a section on the water supply, by H. S. Gale. 1908. 61 pp., 4 pls. 20c.

Describes the geology and contains a geologic map of an area including approximately Tps. 1, 2, and 3 N., Rs. 101, 102, and 103 W., 6th principal meridian. Discusses the water supplies in this area, including artesian wells (p. 58).

*352. Geologic reconnaissance of a part of western Arizona, by W. T. Lee, with notes on the igneous rocks of western Arizona, by Albert Johannsen. 1908. 99 pp., 11 pls. 25c.

Describes the geography and geology and contains a geologic sketch map of western Arizona north of longitude 33° 30′, including the valley of Colorado River and Hualpai, Big Sandy, Detrital-Sacramento, Williams, and McMullen valleys. Contains a section on water supplies, which includes well data and discussion of ground-water prospects.

364. Geology and mineral resources of the Laramie Basin, Wyo. (a preliminary report), by N. H. Darton and C. E. Siebenthal. 1909. 81 pp., 8 pls. 20c.

Describes the geology and contains a geologic map. Includes a section on ground water (pp. 67-78), in which are given well data and 6 water analyses. A part of the area is covered by Geologic Folio 173, which also contains information on ground water.

395. Radioactivity of the thermal waters of Yellowstone National Park, by Herman Schlundt and R. B. Moore. 1909. 35 pp., 4 pls. 10c.

Describes the apparatus and methods used and presents and discusses the results of the experiments.

435. A reconnaissance of parts of northwestern New Mexico and northern Arizona, by N. H. Darton. 1910. 88 pp., 17 pls. 35c.

Describes the geology and contains a geologic map of the region. Includes data in regard to wells at 24 stations on the Atchison, Topeka & Santa Fe R. R. (pp. 75-81).

438. Geology and mineral resources of the St. Louis quadrangle, Mo.-Ill., by N. M. Fenneman. 1911. 73 pp., 6 pls. 25c.

Describes the geology and contains a geologic map of a rectangular area 31 miles east and west by 17 miles north and south, including the city of St. Louis. Discusses the water resources, including springs, flowing wells, and deep wells ending in Carboniferous and Ordovician formations (pp. 65-69). The part of this area that lies in Illinois is also covered by Bulletin 5 of the Illinois Geographical Survey. (See S 3.)

447. Mineral resources of Johnstown, Pa., and vicinity, by W. C. Phalen and Lawrence Martin. 1911. 142 pp., 7 pls. 25c.

Describes the geology and contains a map of the Johnstown quadrangle showing structure contours. Includes a very brief description of water supplies and ground-water conditions (pp. 136-137), which is reprinted in Geologic Folio 174, covering the same quadrangle.

*471. Contributions to economic geology, 1910, Part II, Mineral fuels; M. R. Campbell, geologist in charge. 1912. 663 pp., 62 pls. $1.05.

Issued also in separate chapters. The following paper contains information on ground water: *(a) The Powder River oil field, Wyo., by C. H. Wegemann (pp. 56-75). Describes the geology and contains a geologic map of a quadrangular area which includes Tps. 40-42 N., R. 81 W., and portions of adjoining townships. Contains brief notes on water supplies, including water-bearing formations (pp. 58, 59).

*479. The geochemical interpretation of water analyses, by Chase Palmer. 1911. 31 pp. 5c.

Discusses the expression of chemical analyses and the chemical character and properties of natural waters. Gives a classification of waters based on property values and reacting values, and discusses the character of the waters of certain rivers as interpreted from the analyses. Discusses also the relation of the properties of water to geologic formations, silica in river water, and the character of the water of Mississippi River, the Great Lakes, and St. Lawrence River as indicated by chemical analyses.

491. The data of geochemistry (second edition) by F. W. Clarke. 1911. 782 pp.

Superseded by Bulletin 616.

506. Geology and mineral resources of the Peoria quadrangle, Ill., by J. A. Udden. 1912. 103 pp., 9 pls. 25c.

Describes the physiography and geology of a 15-minute quadrangle that includes the cities of Peoria and Pekin. Contains detailed well records and a section on water resources, in which are discussed the water-bearing formations, and the quality, quantity, head, temperature, and use of the artesian waters (pp. 90-97). Includes 8 chemical analyses and maps showing the geology and locations of artesian wells.

*529. The enrichment of sulphide ores, by W. H. Emmons. 1913. 260 pp. 20c.

Contains a section on underground circulation (pp. 26-31), in which are discussed the "vadose" and deeper circulation and the region of nearly stagnant waters. Contains also 37 analyses of mine waters with discussion (pp. 60-74) and a discussion of chemical changes in descending sulphate waters (pp. 89-91) and related subjects. See also Bulletin 625.

*530. Contributions to economic geology, 1911, Part I, Metals and nonmetals except fuels; Waldemar Lindgren, chief geologist. 1913. 400 pp., 7 pls. 30c.

Issued also in separate chapters. The following papers relate in part to ground water:

*(*b*) The occurrence of potash salts in the bitterns of the eastern Unites States, by W. C. Phalen (pp. 313-329). Includes brief statements in regard to the stratigraphic occurrence and origin of salt water in New York, Michigan, Ohio, West Virginia, Kansas, and Louisiana; also contains analyses.

(*r*) Salines in Silver Peak Marsh, Nev., by R. B. Dole (pp. 330-345). Includes records of 14 borings, 8 to 55 feet deep, a description of methods used in boring, and analyses of water from these holes and from wells and springs in the vicinity.

*531. Contributions to economic geology, 1911, Part II, Mineral fuels; M. R. Campbell, geologist in charge. 1913. 361 pp., 24 pls. 45c.

Issued also in separate chapters. The following papers contain information on ground water.

*(*c*) Geology and petroleum resources of the De Beque oil field, Colo., by E. G. Woodruff (pp. 54-68, Pl. VI). Contains a description of the geology and a geologic map of a square area covering Tps. 7 and 8 S., Rs. 97 and 98 W., in the vicinity of De Beque, in Mesa and Garfield counties. Includes a brief statement on artesian water in the area (p. 61).

*(*d*) Geologic structure of the Punxsutawney, Curwensville, Houtzdale, Barnesboro, and Patton quadrangles, central Pennsylvania, by G. H. Ashley, and M. R. Campbell (pp. 69-89, Pls. VII-VIII). Discusses the geologic structure of the five quadrangles named and includes a map showing structure contours. It contains a brief statement in regard to shallow and deep wells and artesian prospects (pp. 88-89). The ground water in the Barnesboro and Patton quadrangles is also briefly described in Geologic Folio 189, and the ground water in these two quadrangles and in the Curwensville quadrangle is briefly described in Water Supply Paper 110.

*540. Contributions to economic geology, 1912, Part I, Metals and nonmetals except fuels; David White, chief geologist. 1914. 563 pp., 11 pls. 45c.

Issued also in separate chapters. The following papers contain information on ground water:

*(*n*) Prospecting for potash in Death Valley, Cal., by H. S. Gale (pp. 407-415). Includes detailed sections of five wells, 30 to 70 feet deep, with data in regard to their waters, practically all of which are salty, as is shown by the analyses given.

Potash tests at Columbus Marsh, Nev., by H. S. Gale (pp. 422-427). Includes detailed sections of two wells, 32 and 82 feet deep, respectively, with data in regard to their waters, some of which are not salty.

*(*p*) Potash in western saline deposits, by J. H. Hance (pp. 457-469). Gives total solids in waters from various wells and springs in the drainage basins of Railroad Valley, Fourmile Flat, and Dixie Salt Marsh, in Nevada, and the record of a 305-foot well at Adamana, Ariz.

*541. Contributions to economic geology, 1912, Part II, Mineral fuels; M. R. Campbell, geologist in charge. 1914. 532 pp., 29 pls. 50c.

Issued also in separate chapters. The following paper contains information on ground water:

(*d*) Oil and gas near Green River, Grand County, Utah, by C. T. Lupton (pp. 115-133, Pl. VI). Describes the geology and contains a geologic map of an area of about 300 square miles southeast of the town of Green River. Contains meager data in regard to wells, water supplies, and artesian conditions (pp. 117-123).

*543. Geology and geography of a portion of Lincoln County, Wyo., by A. R. Schultz. 1914. 141 pp., 11 pls. 50c.

Describes the geology and contains a geologic map of an area in the central part of Lincoln County, between Green River and the Salt River Range (Tps. 22-39 N., Rs. 113-117 W.). Includes a brief discussion of ground water and artesian prospects (pp. 134, 135).

575. Geology of the Standing Rock and Cheyenne River Indian reservations, North and South Dakota, by W. R. Calvert, A. L. Beekly, V. H. Barnett, and M. A. Pishel. 1914. 49 pp., 8 pls. 15c.

Covers an area lying west of Missouri River, north of Cheyenne River, and south of Cannonball River, and extending westward to 102d meridian. Describes the geology and contains a geologic map of the area. Includes a brief discussion of the water in the Dakota and Fox Hills sandstones and in other formations (pp. 24-25).

*582. Mineral deposits of the Santa Rita and Patagonia mountains, Ariz., by F. C. Schrader, with contributions by J. M. Hill. 1915. 373 pp., 25 pls. 50c.

Includes a brief statement in regard to water supplies from both surface and underground sources (pp. 364–367).

606. Origin of the zinc and lead deposits of the Joplin region, Missouri, Kansas, and Oklahoma, by C. E. Siebenthal. 1915. 283 pp., 11 pls. 25c.

A theoretical treatise which relates to underground circulation in the Ozark region. Discusses artesian circulation and flowing wells (pp. 33–37), geochemical interpretation of water analyses, and acidity, neutrality, and alkalinity of natural waters (pp. 81–88). Reviews, discusses, and classifies analyses of zinc-bearing and related waters from various parts of the United States and from foreign countries (pp. 88–155).

616. The data of geochemistry (third edition), by F. W. Clarke. 1915. 821 pp. 45c.

Earlier editions were published as Bulletins 330 and 491. Contains a discussion of the statement and interpretation of water analyses, and a chapter on "Mineral wells and springs" (pp. 179–216). Discusses the definition and classification of mineral waters, changes in the composition of water, deposits of calcareous, ocherous, and siliceous materials made by water, vadose and juvenile waters, and thermal springs in relation to volcanism. Describes the different kinds of ground water and gives typical analyses. Includes a brief bibliography of papers containing water analyses.

618. Geology and underground water of Luna County, N. Mex., by N. H. Darton. 1916. 188 pp., 13 pls.

Describes the geography and geology, the mineral resources, the water supplies from streams, springs, and wells, and the irrigation development from surface and ground waters. Discusses the source, quantity, and quality of the ground waters and the extent of the water-bearing strata and gives well data by townships. Includes maps showing the geology, the contours of the water table, and the depths to ground water.

*621. Contributions to economic geology, 1915, Part II, Mineral fuels; M. R. Campbell and David White, geologists in charge. 1916. 375 pp., 25 pls. 60c.

Issued also in separate chapters. The following chapters contain information on ground water:

*(*e*) A reconnaissance in Palo Pinto County, Tex., with special reference to oil and gas, by C. H. Wegemann (pp. 51–59). Gives a brief description of the geology of the county with a note on the prospects of obtaining water of good quality from deep sources.

*(*l*) Oil and gas near Basin, Big Horn County, Wyo., by C. T. Lupton (pp. 157–190, Pl. XVII). Describes the geology and contains a geologic map of parts of Tps. 50–52 N., Rs. 92 and 93 W. Includes a brief description of the water supplies and of the water-bearing sand with a table giving percentages of oil and gas wells that obtained water in each of these sand strata (pp. 164–166). It also includes well records that contain some data in regard to water (pp. 186–189).

625. The enrichment of ore deposits, by W. H. Emmons. 1917. 530 pp., 7 pls.

This paper is a revision of Bulletin 529 with a somewhat enlarged scope.

627. The lignite field of northwestern South Dakota, by D. E. Winchester, C. J. Hares, E. R. Lloyd, and E. M. Parks. 1916. 169 pp., 11 pls. 25c.

Describes the geology and contains geologic maps of Harding and Perkins counties. Describes the drainage and water supply and contains a small amount of data on deep wells not given in Water-Supply Paper 227.

628. Geology and coal resources of Castle Valley, in Carbon, Emery, and Sevier counties, Utah, by C. T. Lupton. 1916. 88 pp., 12 pls. 20c.

Describes the geology and contains a geologic map of an area lying between the Wasatch Plateau and the San Rafael Swell, in east-central Utah, and extending from the vicinity of Mounds, on the Denver & Rio Grande Railroad, southwestward about 80 miles. Describes the drainage and water resources, including the prospects of finding water in the Dakota sandstone and underlying McElmo formation.

641. Contributions to economic geology, 1916, Part II, Mineral fuels; David White, G. H. Ashley, and M. R. Campbell, geologists in charge.

Issued also in separate chapters. The following chapters contain information on ground water:

(*b*) The oil and gas geology of the Foraker quadrangle, Osage County, Okla., by K. C. Heald (pp. 17-48, Pls. II-III). Contains, on page 20, a brief statement in regard to ground-water conditions.

(*i*) Anticlines in central Wyoming, by C. J. Hares (pp. 233-280, Pl. XXIII). Covers nearly 5,000 square miles in Natrona and Fremont counties, west of Casper and southeast of Lander. Contains, on pages 235 and 236, a brief discussion of the water supply, including statements regarding various hot springs, springs of large size, sulphur springs, and other mineral springs, also a statement regarding water-bearing formations and artesian prospects. Includes a geologic map.

647. The Bull Mountain coal fields, Musselshell and Yellowstone counties, Mont., by L. H. Woolsey, R. W. Richards, and C. T. Lupton. 1917. 218 pp., 36 pls.

Gives detailed data regarding water supplies, including ground water, for the following townships: Tps. 5-8 N., R. 24 E.; Tps. 5-8 N., R. 25 E.; Tps. 5-8 N., R. 26 E.; Tps. 5-9 N., R. 27 E.; Tps. 5-9 N., R. 28 E.; Tps. 5-9 N., R. 29 E.; Tps. 5-9 N., R. 30 E.; Tps. 5-9 N., R. 31 E.; T. 8 N., R. 32 E. See pages 16, 17, 65-214.

653. Chemical relations of the oil-field waters in San Joaquin Valley, Cal., by G. S. Rogers. 1917. 119 pp.

Discusses water-bearing sands and dry sands in oil fields, the origin of salt water, and the relation of salt water to the occurrence of oil and to geologic structure in oil fields. Classifies the oil-field waters and gives the distribution of their principal constituents. Discusses the chemical relation between water and the hydrocarbons and the significance of water analyses in prospecting for oil. Gives 80 analyses of ground waters in the Coalinga, Kern River, Lost Hills, McKittrick, Midway, and Sunset oil fields, Cal.

656. Anticlines in the southern part of the Big Horn Basin, Wyo., a preliminary report on the occurrence of oil, by D. F. Hewett and C. T. Lupton. 1917. 192 pp., 32 pls.

Covers a large region in northwestern Wyoming, west of the Big Horn Mountains. Gives detailed data regarding surface waters, springs, wells, and ground-water prospects in the numerous anticlinal areas described in the report. See pages 15, 16, 56-188. Includes a geologic map and section.

658. Geologic structure in the Cushing oil and gas field, Okla., and its relation to the oil, gas, and water, by C. H. Beal. 1917. 64 pp., 11 pls.

Discusses, on pp. 39, 44-61, the relation of ground water to bodies of oil and gas and to oil and gas bearing structures. Distinguishes "top water," "bottom water," and "edge water." Discusses the surfaces that form the contacts between bodies of ground water and bodies of oil or gas and differentiates these from ordinary water tables. Includes diagram showing movement of water into oil wells. Incidentally gives ground-water data of local value.

661. Contributions to economic geology, 1917, Part II, Mineral fuels; David White, G. H. Ashley, and M. R. Campbell, geologists in charge. 1918. 328 pp., 29 pls.

Issued also in separate chapters. The following chapter contains information on ground water:

(*d*) The Irvine oil field, Estill County, Ky., by E. W. Shaw (pp. 141-191; Pls. XI-XV). Discusses, on pages 176-179, the relation of ground water to the oil in this field, the character of so-called "dry sands," the mineral composition of the waters, and the relation of mineral composition to the origin of the water and oil. Includes four analyses of waters from the Estill Springs.

691. Contributions to economic geology, 1918. Part II, Mineral fuels; David White, G. H. Ashley, and M. R. Campbell, geologists in charge.

Issued also in separate chapters. The following chapter contains information on ground water:

(*c*) Geologic structure of the northwestern part of the Pawhuska quadrangle, Okla., by K. C. Heald (pp. 57-100, Pls. XIII-XV). Covers an area just south of the Kansas line and about 90 miles west of the Missouri line (T. 29 N., Rs. 8 and 9 E., and large parts of T. 28 N., R. 9 E.; T. 29 N., R. 8 E.; and T. 27 N., R. 8 E.). Discusses very briefly, on page 60, the ground-water conditions and the prospects of obtaining potable supplies in the sandstones penetrated in the oil wells. Contains a brief general statement regarding the quality of the ground waters.

## REPORTS ON MINERAL RESOURCES.

The report on mineral resources for the calendar years 1883 and 1884 and the reports for each subsequent year contain sections on mineral waters, which give statistics, by calendar years, of production, importation, and exportation, lists of mineral springs, and other information in regard to the trade in the waters of the United States that are sold for medicinal or table use. The statistics are given largely by States.

The reports on mineral waters for successive years were prepared by the following authors:

1883–1900, inclusive, by A. C. Peale.
1901–1904, inclusive, anonymous.
1905, by M. L. Fuller.
1906–1909, inclusive, by Samuel Sanford.
1910–1912, inclusive, by G. C. Matson.
1913–1915, inclusive, by R. B. Dole.
1916, by A. J. Ellis.

In addition to the annual statistics, these reports contain the following papers relating to mineral waters:

*(M R 1882) Mineral Resources of the United States, 1882. 1883. 813 pp. 50c.

*(a) The divining rod, by R. W. Raymond (pp. 610–626). Gives a vivid historical review and discussion of the so-called "divining rod," which has been supposed to have virtue for finding ground water and other minerals, as well as for detecting criminals, etc.

*(M R 1905) Mineral Resources of the United States, 1905. 1906. 1403 pp.

Bibliography of mineral waters, by A. C. Peale (pp. 1308–1312). Includes a general bibliography and a bibliography for the United States, 1903–1905.

*(M R 1911) Mineral Resources of the United States, 1911, Part II, Nonmetals. 1912. 1224 pp., 9 pls. $1.

*(n) The concentration of mineral water in relation to therapeutic activity, by R. B. Dole (pp. 1175–1192). Discusses mineral constituents in relation to physiological reactions, minimum doses of inorganic substances, the therapeutic action of certain inorganic radicles, and tolerance for mineral matter in drinking water.

*(M R 1913) Mineral Resources of the United States, 1913, Part II, Nonmetals, 1914. 1617 pp., 9 pls. 80c.

(h) Published analyses of American mineral waters, by R. B. Dole (pp. 433–434). An incomplete bibliography of papers containing analyses of mineral waters.

Radioactivity of mineral waters, by R. B. Dole (pp. 435–440). Gives the radioactivity of 52 well-known waters from springs in Europe and the United States, compares their strength with that of radioactive compounds used in medical practice, and discusses the therapeutic uses of radioactive waters. Includes an incomplete bibliography of publications on radium, radioactivity, and radiotherapy.

(M R 1914) Mineral Resources of the United States, 1914, Part II, Nonmetals, 1916. 1122 pp., 5 pls.

A historical sketch of the mineral-water trade, by R. B. Dole (pp. 215–219). Tabulates and discusses the domestic production and importation from 1883 to 1914 and includes diagrams showing the annual production and the price during this period.

(M R 1916) Mineral Resources of the United States, 1916, Part II, Nonmetals. 1918.

Comparison of American and European mineral waters, by A. A. Chambers. 11 pp. Compares the analyses of certain chalybeate, carbonate, sulphide, chloride, and sulphate spring waters in the United States with the analyses of well-known mineral waters of Europe of similar types. Concludes that the counterparts of European waters can in general be found in this country. Contains a brief bibliography of mineral waters, chiefly those from American springs.

## GEOLOGIC FOLIOS.

| No. | Name of folio and year of publication. | State. | Author. | Boundaries. | | | | | | | | Price. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | North. | | South. | | East. | | West. | | |
| | 1894. | | | ° | ′ | ° | ′ | ° | ′ | ° | ′ | *Cents.* |
| *13 | Fredericksburg | Md.-Va. | Darton, N. H | 38 | 30 | 38 | 00 | 77 | 00 | 77 | 30 | ...... |
| | 1395. | | | | | | | | | | | |
| *17 | Marysville | Cal | Lindgren, Waldemar; Turner, H. W | 39 | 30 | 39 | 00 | 121 | 30 | 122 | 00 | ...... |
| | 1896. | | | | | | | | | | | |
| 23 | Nomini [a] | Md.-Va. | Darton, N. H | 38 | 30 | 38 | 00 | 76 | 30 | 77 | 00 | 5 |
| *24 | Three Forks [b] | Mont | Peale, A. C | 46 | 00 | 45 | 00 | 111 | 00 | 112 | 00 | ...... |
| | 1897. | | | | | | | | | | | |
| 36 | Pueblo [a] | Colo | Gilbert, G. K | 38 | 30 | 38 | 00 | 104 | 30 | 105 | 00 | 5 |
| *39 | Truckee [b] | Cal | Lindgren, Waldemar. | 39 | 30 | 39 | 00 | 120 | 00 | 120 | 30 | ...... |
| | 1898. | | | | | | | | | | | |
| 42 | Nueces [a] | Tex | Hill, R. T.; Vaughan, T. W. | 30 | 00 | 29 | 30 | 100 | 00 | 100 | 30 | 5 |
| *45 | Boise | Idaho | Lindgren, Waldemar. | 44 | 00 | 43 | 30 | 116 | 00 | 116 | 30 | ...... |
| | 1899. | | | | | | | | | | | |
| *55 | Fort Benton | Mont | Weed, W. H | 48 | 00 | 47 | 00 | 110 | 00 | 111 | 00 | ...... |
| *56 | Little Belt Mountains. [b] | do | do | 47 | 00 | 46 | 00 | 110 | 00 | 111 | 00 | ...... |
| *58 | Elmoro [a] | Colo | Hills, R. C | 37 | 30 | 37 | 00 | 104 | 00 | 104 | 30 | ...... |
| | 1900. | | | | | | | | | | | |
| *64 | Uvalde | Tex | Vaughan, T. W | 29 | 30 | 29 | 00 | 99 | 30 | 100 | 00 | ...... |
| *66 | Colfax | Cal | Lindgren, Waldemar. | 39 | 30 | 39 | 00 | 120 | 30 | 121 | 00 | ...... |
| 67 | Danville | Ill.-Ind | Campbell, M. R.; Leverett, Frank. | 40 | 15 | 40 | 00 | 87 | 30 | 87 | 45 | 5 |
| 68 | Walsenburg [a] | Colo | Hills, R. C | 38 | 00 | 37 | 30 | 104 | 30 | 105 | 00 | 5 |
| | 1901. | | | | | | | | | | | |
| *70 | Washington [a] | D. C.-Va.-Md. | Darton, N. H.; Keith, Arthur. | 39 | 00 | 38 | 45 | 76 | 45 | 77 | 15 | ...... |
| *71 | Spanish Peaks [a]. | Colo | Hills, R. C | 37 | 30 | 37 | 00 | 104 | 30 | 105 | 00 | ...... |
| | 1902. | | | | | | | | | | | |
| *76 | Austin | Tex | Hill, R. T.; Vaughan, T. W. | 30 | 30 | 30 | 00 | 97 | 30 | 98 | 00 | ...... |
| *80 | Norfolk | Va.-N. C | Darton, N. H | ...... | | ...... | | ...... | | ...... | | ...... |
| *81 | Chicago | Ill.-Ind | Alden, W. C | 42 | 00 | 41 | 30 | 87 | 30 | 88 | 00 | ...... |
| *83 | New York City | N. Y.-N. J | Merrill, F. J. H.; Darton, N. H.; Hollick, Arthur; Salisbury, R. D.; Dodge, R. E.; Willis, Bailey; Pressey, H. A. | 41 | 00 | 40 | 30 | 73 | 45 | 74 | 15 | ...... |
| 84 | Ditney | Ind | Fuller, M. L.; Ashley, G. H. | 38 | 30 | 38 | 00 | 87 | 00 | 87 | 30 | 5 |
| 85 | Oelrichs [a] | S. Dak.-Nebr. | Darton, N. H | 43 | 30 | 43 | 00 | 103 | 00 | 103 | 30 | 5 |
| | 1903. | | | | | | | | | | | |
| 86 | Ellensburg | Wash | Smith, G. O | 47 | 00 | 46 | 30 | 120 | 30 | 121 | 00 | 5 |
| 87 | Camp Clarke | Nebr | Darton, N. H | 42 | 00 | 41 | 30 | 103 | 00 | 103 | 30 | 5 |
| 88 | Scotts Bluff | do | do | 42 | 00 | 41 | 30 | 103 | 30 | 104 | 00 | 5 |
| 92 | Gaines [b] | Pa.-N. Y | Fuller, M. L.; Alden, W. C. | 42 | 00 | 41 | 45 | 77 | 45 | 78 | 00 | 5 |
| 96 | Olivet [a] | S. Dak | Todd, J. E | 43 | 30 | 43 | 00 | 97 | 30 | 98 | 00 | 5 |
| 97 | Parker [a] | do | do | 43 | 30 | 43 | 00 | 97 | 00 | 97 | 30 | 5 |
| 99 | Mitchell [a] | do | do | 44 | 00 | 43 | 30 | 98 | 00 | 98 | 30 | 5 |
| 100 | Alexandria [a] | do | Todd, J. E.; Hall, C. M. | 44 | 00 | 43 | 30 | 97 | 30 | 98 | 00 | 5 |

[a] Includes map showing artesian or other ground-water conditions.
[b] Information on mineral water only.

*Geologic folios*—Continued.

| No. | Name of folio and year of publication. | State. | Author. | Boundaries. | | | | | | | | Price. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | North. | | South. | | East. | | West. | | |
| | | | | ° | ′ | ° | ′ | ° | ′ | ° | ′ | *Cents.* |
| | 1904. | | | | | | | | | | | |
| 101 | San Luis [a] | Cal. | Fairbanks, H. W. | 35 | 30 | 35 | 00 | 120 | 30 | 121 | 00 | 5 |
| 102 | Indiana | Pa. | Richardson, G. B. | 40 | 45 | 40 | 30 | 79 | 00 | 79 | 15 | 5 |
| 103 | Nampa | Idaho-Oreg. | Lindgren, Waldemar; Drake, N. F. | 44 | 00 | 43 | 30 | 116 | 30 | 117 | 00 | 5 |
| 104 | Silver City | Idaho | do. | 43 | 30 | 43 | 00 | 116 | 30 | 117 | 00 | 5 |
| 105 | Patoka | Ind.-Ill. | Fuller, M. L.; Clapp, F. G. | 38 | 30 | 38 | 00 | 87 | 30 | 88 | 00 | 5 |
| 106 | Mount Stuart | Wash. | Smith, G. O. | 47 | 30 | 47 | 00 | 120 | 30 | 121 | 00 | 5 |
| 107 | Newcastle [b] | Wyo.-S. Dak. | Darton, N. H. | 44 | 00 | 43 | 30 | 104 | 00 | 104 | 30 | 5 |
| 108 | Edgemont [b] | S. Dak.-Nebr. | Darton, N. H.; Smith, W. S. T. | 43 | 30 | 43 | 00 | 103 | 30 | 104 | 00 | 5 |
| *111 | Globe | Ariz. | Ransome, F. L. | 33 | 30 | 33 | 15 | 110 | 45 | 111 | 00 | ...... |
| 112 | Bisbee | do. | do. | 31 | 30 | ([c]) | | 109 | 45 | 110 | 00 | 25 |
| 113 | Huron [b] | S. Dak. | Todd, J. E. | 44 | 30 | 44 | 00 | 98 | 00 | 98 | 30 | 5 |
| 114 | De Smet [b] | do. | Todd, J. E.; Hall, C. M. | 44 | 30 | 44 | 00 | 97 | 30 | 98 | 00 | 5 |
| | 1905. | | | | | | | | | | | |
| 117 | Casselton-Fargo [b] | N. Dak.-Minn. | Hall, C. M.; Willard, D. E. | 47 | 00 | 46 | 30 | 96 | 30 | 97 | 30 | 5 |
| *120 | Silverton [d] | Colo. | Cross, Whitman; Howe, Ernest; Ransome, F. L. | 38 | 00 | 37 | 45 | 107 | 30 | 107 | 45 | ...... |
| *121 | Waynesburg | Pa. | Stone, R. W. | 40 | 00 | 39 | 45 | 80 | 00 | 80 | 15 | ...... |
| 122 | Tahlequah | Okla.-Ark. | Taff, J. C. | 36 | 00 | 35 | 30 | 94 | 30 | 95 | 00 | 5 |
| 123 | Elders Ridge | Pa. | Stone, R. W. | 40 | 45 | 40 | 30 | 79 | 15 | 79 | 30 | 5 |
| 124 | Mount Mitchell | N. C.-Tenn. | Keith, Arthur | 36 | 00 | 35 | 30 | 82 | 00 | 82 | 30 | 5 |
| *127 | Sundance [b] | Wyo.-S. Dak. | Darton, N. H. | 44 | 30 | 44 | 00 | 104 | 00 | 104 | 30 | ...... |
| *128 | Aladdin [b] | Wyo.-S. Dak.-Mont. | Darton, N. H.; O'Harra, C. C. | 45 | 00 | 44 | 30 | 104 | 00 | 104 | 30 | ...... |
| *129 | Clifton | Ariz. | Lindgren, Waldemar. | 33 | 15 | 33 | 00 | 109 | 15 | 109 | 30 | ...... |
| | 1906. | | | | | | | | | | | |
| *132 | Muscogee | Okla. | Taff, J. A. | 36 | 00 | 35 | 30 | 95 | 00 | 95 | 30 | ...... |
| *133 | Ebensburg | Pa. | Butts, Chas. | 40 | 30 | 40 | 15 | 78 | 30 | 78 | 45 | ...... |
| *135 | Nepesta [b] | Colo. | Fisher, C. A. | 38 | 30 | 38 | 00 | 104 | 00 | 104 | 30 | ...... |
| 136 | St. Marys | Md.-Va. | Shattuck, G. B.; Miller, B. L. | 38 | 30 | 38 | 00 | 76 | 00 | 76 | 30 | 5 |
| 137 | Dover | Del.-Md.-N. J. | Miller, B. L. | 39 | 30 | 39 | 00 | 75 | 30 | 76 | 00 | 5 |
| *138 | Redding | Cal. | Diller, J. S. | 41 | 00 | 40 | 30 | 122 | 00 | 122 | 30 | ...... |
| *140 | Milwaukee special. | Wis. | Alden, W. C. | 43 | 09 | 42 | 54 | 87 | 50 | 88 | 05 | ...... |
| *141 | Bald Mountain-Dayton. | Wyo. | Darton, N. H.; Salisbury, R. D. | 45 | 00 | 44 | 30 | 107 | 00 | 108 | 00 | ...... |
| *142 | Cold Peak-Fort McKinney. | do. | do. | 44 | 30 | 44 | 00 | 106 | 30 | 107 | 30 | ...... |
| | 1907. | | | | | | | | | | | |
| *144 | Amity | Pa. | Clapp, F. G. | 40 | 15 | 40 | 00 | 80 | 00 | 80 | 15 | ...... |
| *145 | Lancaster-Mineral Point. | Wis.-Iowa-Ill. | Grant, U. S.; Burchard, E. F. | 43 | 00 | 42 | 30 | 90 | 00 | 91 | 00 | ...... |
| 146 | Rogersville | Pa. | Clapp, F. G. | 40 | 00 | 39 | 45 | 80 | 15 | 80 | 30 | 5 |
| 147 | Pisgah | N. C.-S. C. | Keith, Arthur | 35 | 30 | 35 | 00 | 82 | 30 | 83 | 00 | 5 |
| 148 | Joplin district | Mo.-Kans. | Smith, W. S. T.; Siebenthal, C. E. | 37 | 15 | 37 | 00 | 94 | 15 | 94 | 45 | 50 |
| *149 | Penobscot Bay | Maine | Smith, G. O.; Bastin, E. S.; Brown, C. W. | 44 | 30 | 44 | 00 | 68 | 30 | 69 | 00 | ...... |
| *150 | Devils Tower [b] | Wyo. | Darton, N. H.; O'Harra, C. C. | 45 | 00 | 44 | 30 | 104 | 30 | 105 | 00 | ...... |
| *151 | Roan Mountain. | Tenn.-N. C. | Keith, Arthur | 36 | 30 | 36 | 00 | 82 | 00 | 82 | 30 | ...... |
| *152 | Patuxent [b] | Md.-D. C. | Shattuck, G. B.; Miller, B. L.; Bibbins, Arthur. | 39 | 00 | 38 | 30 | 76 | 30 | 77 | 00 | ...... |
| *153 | Ouray | Colo. | Cross, Whitman; Howe, Ernest; Irving, J. D. | 38 | 15 | 38 | 00 | 107 | 30 | 107 | 45 | ...... |
| *154 | Winslow | Ark.-Okla. | Purdue, A. H. | 36 | 00 | 35 | 30 | 94 | 00 | 94 | 30 | ...... |

[a] Information on mineral water only.
[b] Includes map showing artesian or other ground-water conditions.
[c] International boundary.
[d] Discusses mineral waters associated with the ore deposits and ground water in relation to the zone of oxidized ore and in relation to mine drainage.

## *Geologic folios*—Continued.

| No. | Name of folio and year of publication. | State. | Author. | Boundaries. | | | | | | | | Price. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | North. | | South. | | East. | | West. | | |
| | 1908. | | | ° | ′ | ° | ′ | ° | ′ | ° | ′ | *Cents.* |
| *155 | Ann Arbor[a] | Mich | Russell, I. C.; Leverett, Frank. | 42 | 30 | 42 | 00 | 83 | 30 | 84 | 00 | ...... |
| 156 | Elk Point[a] | S. Dak.-Nebr.-Iowa. | Todd, J. E | 43 | 00 | 42 | 30 | 96 | 30 | 97 | 00 | 5 |
| *157 | Passaic | N. J.-N. Y | Darton, N. H.; Bayley, W. S.; Salisbury, R. D.; Kümmel, H. B. | 41 | 00 | 40 | 30 | 74 | 00 | 74 | 30 | ...... |
| 158 | Rockland | Maine | Bastin, E. S | 44 | 15 | 44 | 00 | 69 | 00 | 69 | 15 | 5 |
| 159 | Independence | Kans | Schrader, F. C | 37 | 30 | 37 | 00 | 95 | 30 | 96 | 00 | 5 |
| 160 | Accident-Grantsville. | Md.-Pa.-W. Va. | Martin, G. C | 39 | 45 | 39 | 30 | 79 | 00 | 79 | 30 | 5 |
| *161 | Franklin Furnace. | N. J | Spencer, A. C.; Kümmel, H. B.; Wolff, J. E.; Salisbury, R. D.; Palache, Charles. | 41 | 15 | 41 | 00 | 74 | 30 | 74 | 45 | ...... |
| | 1909. | | | | | | | | | | | |
| *162 | Philadelphia | Pa.-N. J.-Del. | Bascom, Florence; Clark, W. B.; Darton, N. H.; Kümmel, H. B.; Salisbury, R. D.; Miller, B. L.; Knapp, G. N. | 40 | 15 | 39 | 45 | 75 | 00 | 75 | 30 | ...... |
| *163 | Santa Cruz | Cal | Branner, J. C.; Newsom, J. F.; Arnold, Ralph. | 37 | 30 | 36 | 55 | 122 | 00 | 122 | 30 | ...... |
| 164 | Belle Fourche[a] | S. Dak | Darton, N. H.; O'Harra, C. C. | 45 | 00 | 44 | 30 | 103 | 30 | 104 | 00 | 5 |
| 165 | Aberdeen-Redfield.[b] | do | Todd, J. E | 45 | 30 | 44 | 30 | 98 | 00 | 99 | 00 | 5 |
| 166 | El Paso | Tex | Richardson, G. B | 32 | 00 | 31 | 30 | 106 | 00 | 106 | 35 | 5 |
| *167 | Trenton | N. J.-Pa | Bascom, Florence; Darton, N. H.; Kümmel, H. B.; Clark, W. B.; Salisbury, R. D. | 40 | 30 | 40 | 00 | 74 | 30 | 75 | 00 | ...... |
| 168 | Jamestown-Tower.[a] | N. Dak | Willard, D. E.; Williams, H. S. | 47 | 00 | 46 | 30 | 97 | 30 | 99 | 00 | 5 |
| *169 | Watkins Glen-Catatonk. | N. Y | Tarr, R. S.; Kindle, E. M. | 42 | 30 | 42 | 00 | 76 | 00 | 77 | 00 | ...... |
| 170 | Mercersburg-Chambersburg. | Pa | Stose, G. W | 40 | 00 | 39 | 45 | 77 | 30 | 78 | 00 | 5 |
| | 1910. | | | | | | | | | | | |
| 172 | Warren | Pa.-N. Y | Butts, Charles | 42 | 00 | 41 | 45 | 79 | 00 | 79 | 15 | 5 |
| 173 | Laramie-Sherman. | Wyo | Darton, N. H.; Blackwelder, Eliot; Siebenthal, C. E. | 41 | 30 | 41 | 00 | 105 | 00 | 106 | 00 | 5 |
| 174 | Johnstown | Pa | Phalen, W. C | 40 | 30 | 40 | 15 | 78 | 45 | 79 | 00 | 5 |
| 175 | Birmingham | Ala | Butts, Charles | 34 | 00 | 33 | 30 | 86 | 30 | 87 | 00 | 5 |
| | 1912. | | | | | | | | | | | |
| 179 | Pawpaw-Hancock. | W. Va.-Md.-Pa. | Stose, G. W.; Schwartz, C. K. | 39 | 45 | 39 | 30 | 78 | 00 | 78 | 30 | 5 |
| 181 | Bismarck | N. Dak | Leonard, A. G | 47 | 00 | 46 | 30 | 100 | 30 | 101 | 00 | 5 |
| 182 | Choptank[a] | Md | Miller, B. L | 39 | 00 | 38 | 30 | 76 | 00 | 76 | 30 | 5 |
| 183 | Llano-Burnet | Tex | Paige, Sidney | 31 | 00 | 30 | 30 | 98 | 00 | 99 | 00 | 5 |
| 184 | Kenova[c] | Ky.-W. Va.-Ohio. | Phalen, W. C | 38 | 30 | 38 | 00 | 82 | 30 | 83 | 00 | 5 |
| | 1913. | | | | | | | | | | | |
| 185 | Murphysboro-Herrin. | Ill | Shaw, E. W.; Savage, T. E. | 38 | 00 | 37 | 45 | 89 | 00 | 89 | 30 | 25 |
| 186 | Apishapa[a] | Colo | Stose, G. W | 38 | 00 | 37 | 30 | 104 | 00 | 104 | 30 | 5 |
| 187 | Ellijay[b] | Ga.-N. C | LaForge, Laurence; Phalen, W. C. | 35 | 00 | 34 | 30 | 84 | 00 | 84 | 30 | 25 |
| 188 | Tallula-Springfield. | Ill | Shaw, E. W.; Savage, T. E. | 40 | 00 | 39 | 45 | 89 | 30 | 90 | 00 | 25 |
| 189 | Barnesboro-Patton. | Pa | Campbell, M. R.; Clapp, F. G.; Butts, Charles. | 40 | 45 | 40 | 30 | 78 | 30 | 79 | 00 | 25 |
| 190 | Niagara | N. Y | Kindle, E. M.; Taylor, F. B. | 43 | 30 | 43 | 00 | 78 | 30 | 79 | 00 | 50 |

[a] Includes map showing artesian or other ground-water conditions.

[b] Information on mineral water only.

[c] Contains no discussion of ground water but a section and data regarding oil and gas wells which give information as to depth at which salt water is found.

*Geologic folios*—Continued.

| No. | Name of folio and year of publication. | State. | Author. | Boundaries. | | | | | | | | Price. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | North. | | South. | | East. | | West. | | |
| | 1914. | | | ° | ′ | ° | ′ | ° | ′ | ° | ′ | *Cents.* |
| 191 | Raritan | N. J. | Bayley, W. S.; Kümmel, H. B.; Salisbury, R. D. | 41 | 00 | 40 | 30 | 74 | 30 | 75 | 00 | 25 |
| 192 | Eastport | Maine | Bastin, E. S.; Williams, H. S. | 45 | 00 | 44 | 45 | 67 | 00 | 67 | 15 | 25 |
| 193 | San Francisco | Cal | Lawson, A. C. | 38 | 00 | 37 | 30 | 122 | 00 | 122 | 45 | 75 |
| 194 | Van Horn | Tex | Richardson, G. B | 31 | 30 | 31 | 00 | 104 | 30 | 105 | 00 | 25 |
| | 1915. | | | | | | | | | | | |
| 195 | Belleville-Breese | Ill | Udden, J. A.; Shaw, E. W. | 38 | 45 | 38 | 30 | 89 | 30 | 90 | 00 | 25 |
| 197 | Columbus | Ohio | Hubbard, G. D.: Stauffer, C. R.; Bownocker, J. A.; Prosser, C. S.; Cumings, E. R. | 40 | 15 | 39 | 45 | 82 | 45 | 83 | 15 | 25 |
| 198 | Castle Rock | Colo | Richardson, G. B | 39 | 30 | 39 | 00 | 104 | 30 | 105 | 00 | 25 |
| | 1916. | | | | | | | | | | | |
| 199 | Silver City | N. Mex | Paige, Sidney; Darton, N. H. | 33 | 00 | 32 | 30 | 108 | 00 | 108 | 30 | 25 |
| 200 | Galena-Elizabeth. | Ill.-Iowa | Shaw, E. W.; Trowbridge, A. C. | 42 | 30 | 42 | 15 | 90 | 00 | 90 | 30 | 25 |
| 201 | Minneapolis-St. Paul. | Minn | Sardeson, F. W | 45 | 15 | 44 | 45 | 93 | 00 | 93 | 30 | 25 |
| 203 | Colorado Springs | Colo | Finlay, G. I. | 39 | 00 | 38 | 30 | 104 | 30 | 105 | 00 | 25 |
| | 1917. | | | | | | | | | | | |
| 204 | Tolchester | Md | Miller, B. L.; Mathews, E. F.; Bibbins, A. B.; Little, H. P. | 39 | 30 | 39 | 00 | 76 | 00 | 76 | 30 | 25 |
| 205 | Detroit | Mich | Sherzer, W. H | 42 | 30 | 42 | 00 | 82 | 45 | 83 | 30 | 50 |
| 206 | Leavenworth-Smithville. | Mo.-Kans | Hinds, Henry; Greene, F. C. | 39 | 30 | 39 | 15 | 94 | 30 | 95 | 00 | 25 |
| 207 | Deming | N. Mex | Darton, N. H | 32 | 30 | 32 | 00 | 107 | 30 | 108 | 00 | 25 |

## COOPERATIVE REPORTS NOT PUBLISHED BY THE UNITED STATES GEOLOGICAL SURVEY.

(S 1) Report of a reconnaissance in Trans-Pecos Texas, north of the Texas & Pacific Railway, by G. B. Richardson. Texas Univ. Min. Survey Bull. 9; Texas Univ. Bull. 23, Austin, Tex., 1904. 119 pp., 11 pls.

Describes the topography, geology, mineral resources, and ground waters of Toyah, Salt, and Hueco basins, Gypsum Plain, Guadalupe-Delaware Mountains, Diablo Plateau, and Rio Grande Valley. Contains a table of well data, well sections, and water analyses, and includes a map showing the geology and the locations of wells and springs.

(S 2) The underground water resources of Alabama, by E. A. Smith. Alabama Geol. Survey, Montgomery, Ala., 1907. 388 pp., 30 pls.

Describes the geography, geology, and climate of the State. Contains a general discussion in regard to the occurrence, circulation, and recovery of ground water and in regard to artesian wells. Gives detailed descriptions of wells, mineral waters, and ground-water conditions, with discussions of artesian prospects, by provinces, counties, and vicinities. Discusses the chemistry and classification of the waters from the various horizons and contains water analyses. Includes maps showing the geology and the areas of artesian flow.

(S 3) Water resources of the East St. Louis district, by Isaiah Bowman and C. A. Reeds. Illinois State Geol. Survey Bull. 5, Urbana, Ill., 1907. 128 pp., 4 pls.

Discusses the economic features of the district as a manufacturing site and describes the topography and geology and the water supplies from springs, cisterns, streams, lakes, reservoirs, and wells. Discusses underground drainage, fluctuations of the water table, water resources of the Karst, contamination of Karst water, unusual phenomena associated with springs and wells, and artesian conditions. Contains well sections and mineral and sanitary analyses of water. The water resources of a part of this area are also described in U. S. Geological Survey Bulletin 438.

(S 4) A preliminary report on the underground waters of Georgia, by S. W. McCallie. Georgia Geol. Survey Bull. 15, Atlanta, Ga., 1908. 370 pp., 30 pls.

**Describes the physiography and geology of the State and discusses briefly precipitation, evaporation, and absorption by the soil. Describes in general the waters of the various geological formations, and in more detail the ground-water conditions in each county in the Coastal Plain, Crystalline area, and Paleozoic area. Contains numerous analyses of ground waters and discussions of their quality. Includes a chapter entitled "Experiment relating to problems of well contamination at Quitman" and one entitled "Blowing springs and wells of Georgia." Includes a table of data regarding public water supplies and a table of miscellaneous spring records. Also includes a geologic map of Georgia.**

(S 5) The Coastal Plain of North Carolina, by W. B. Clark, B. L. Miller, L. W. Stephenson, B. L. Johnson, and H. N. Parker. North Carolina Geol. and Econ. Survey, vol. 3, Raleigh, N. C., 1912. 552 pp., 42 pls.

**Consists of two parts bound in one volume. Part I describes the physiography and geology; Part II describes the water resources both surface and underground. Part II opens with a bibliography and a general discussion of the ground-water conditions but consists chiefly of detailed descriptions, by counties, of the topography, geology, ground-water conditions, and artesian prospects, with tables giving well data. These county descriptions are followed by a discussion of the quality of the water, by counties, and tables of analyses. The volume contains maps of the Coastal Plain of North Carolina showing the distribution of the surficial deposits and the underlying formations, the position of the basement rocks, and the areas in which potable water can be obtained from the various formations.**

(S 6) Subterranean storage of flood waters by artificial methods in San Bernardino Valley, Cal., by C. H. Lee. Conservation Commission of California Rept. for 1912, Sacramento, Cal., 1912. pp. 335–400, 3 pls.

**Gives history and methods of water spreading and amount of water spread along Santa Ana River and other streams. Gives data in regard to precipitation, run-off, and stream percolation in the San Bernardino Basin. Describes the ground-water reservoir in this basin, giving data on fluctuations of the water table and the artesian head. Discusses ground-water fluctuations in other basins in Southern California and draws conclusions as to the effect of water spreading. Includes a map showing the original area of artesian flow in the San Bernardino Basin and the areas in 1904 and 1912, also locations of wells and of lands used for spreading water.**

(S 7) Ground-water resources of Indian Wells Valley, Cal., by C. H. Lee. Conservation Commission of California Rept. for 1912, Sacramento, Cal., 1912. pp. 401–429, 5 pls.

**A brief report covering an arid valley (also known as Salt Wells Valley) that lies mostly in northeastern Kern County but extends into Inyo and San Barnardino counties and comprises a part of the area included in Tps. 25–27, Rs. 38–40. Gives information in regard to precipitation, stream flow, evaporation of ground water, and water supply available by pumping from wells.**

(S 8) The underground water resources of the Coastal Plain province of Virginia, by Samuel Sanford. Virginia Geol. Survey Bull. 5, Charlottesville, Va., 1913. 361 pp., 1 pl.

**Describes and discusses the topography, geology, origin, occurrence, and emergence of ground water, types of springs and their pollution, artesian conditions, cisterns, collecting tunnels, types of wells, magnetic wells, and freshening of deep water. Gives detailed information on wells and ground-water conditions by counties and contains tables of well data and of analyses of spring and well waters. Includes a map showing the areas of artesian flow and the quality of the ground waters.**

(S 9) The underground and surface water supplies of Wisconsin, by Samuel Weidman and A. R. Schultz. Wisconsin Geol. and Nat. Hist. Survey Bull. 35, Madison, Wis., 1915. 664 pp., 5 pls.

**Describes the geography and geology of the State and the conditions controlling local ground waters and artesian waters. Describes the flowing wells and artesian prospects, the springs and mineral waters, the uses of water supplies, and the quality of water from various geologic sources and from the rivers and lakes of the State. Gives detailed descriptions by counties with well sections and water analyses. Includes maps showing the geology, the surface of the pre-Cambrian rocks, the head of artesian water, and the areas of soft and hard water.**

(S 10) Memorandum on the geology of the ground waters of the Island of Antigua, B. W. I., by T. W. Vaughan. Imperial Dept. Agr. for the West Indies, West Indian Bull., vol. 14, No. 4, 1915. pp. 276–280.

Outlines the physiography and geology of Antigua and their bearing on ground-water conditions. Discusses the prospects of obtaining artesian and other ground waters; also discusses the quality of the ground waters, especially with reference to salt. Includes a sketch map of the island showing the geology. Reference is made to the work of H. A. Tempany, chemist and superintendent of agriculture for the Leeward Islands, who published two papers on the same subject, containing some detailed spring and well data and a number of analyses of ground water. The papers by Tempany are as follows: "The water supply of Antigua" (West Indian Bull., vol. 12, No. 4) and "The ground waters of Antigua" (West Indian Bull., vol. 14, No. 4).

(S 11) Reports on condition of water supply at Savannah, Ga. Mayor of Savannah Ann. Rept., 1915.

Contains the following papers submitted by the United States Geological Survey:

Preliminary report on Savannah Water Supply, by L. W. Stephenson and R. B. Dole. Pp. 1-14.

The water supply of Savannah, Ga., by R. B. Dole. Pp. 15-89.

These papers discuss the yield and head of the artesian wells of Savannah, the consumption of water, the sanitary and chemical quality of the water, and the cost of operation. They give the results of fluorescein tests and several analyses of surface and ground waters. They conclude with recommendations for future developments.

(S 12) Report of the Water Commission of the Territory of Hawaii to the Governor of Hawaii, by G. K. Larrison, A. G. Smith, and T. F. Sedgwick. Honolulu, 1917. 53 pp., map, diagrams, and tables.

Discusses and gives data regarding artesian water on the Island of Oahu, the relation of precipitation to artesian head, the discharge of flowing and pumped wells, the interference of wells, the progress of artesian well boring, and waste of water from artesian wells. Includes a proposed law relating to the use of water from artesian wells. The data were collected by R. C. Rice and R. D. Klise, of the United States Geological Survey, under the direction of T. F. Sedgwick.

## MISCELLANEOUS SPRING RECORDS.

*Miscellaneous records of the discharge of springs in papers not elsewhere listed.*

| Water-Supply Paper. | Pages on which data are given. | Date of measurement. | Name. | State. | Location. | Discharge. |
|---|---|---|---|---|---|---|
| | | | | | | *Sec.-ft.* |
| 27 | 45 | Dec. 20, 1898 | Silver Spring | Fla | Near Ocala | 822 |
| 27 | 45 | Dec. 21, 1898 | Kissingen Spring | do | Bartow | 31 |
| 27 | 45 | Dec. 22, 1898 | Blue Spring | do | Juliet | 778 |
| 27 | 45 | Dec. 23, 1898 | Itchatucknee Spring | do | Near Fort White | 403 |
| 28 | 130 | Mar. 26, 1898 | Barton Spring | Tex | Austin | 20 |
| 28 | 130 | May 3, 1898 | do | do | do | 30 |
| 28 | 130 | do | do | do | do | 31 |
| 28 | 130 | Dec. 23, 1898 | do | do | do | 19 |
| 28 | 130 | Dec. 24, 1898 | do | do | do | 19 |
| 36 | 147 | May 30, 1899 | Dooley Spring | Ga | 3 miles south of Fairmount. | .92 |
| 36 | 147 | do | Drove Mill Spring | do | Near Cash | 16.2 |
| 36 | 147 | do | Baker's mill spring | do | 5 miles south of Fairmount. | 3.9 |
| 36 | 147 | June 24, 1899 | Colina Spring | do | Near Colina | .28 |
| 36 | 147 | do | Arnold Spring | do | 1 mile south of Colina | .38 |
| 36 | 147 | do | J. R. Byrd's spring | do | 2½ miles northwest of Fairmount. | .47 |
| 36 | 147 | do | R. W. Lander's spring | do | 3 miles east of Pinelog | 4.27 |
| 36 | 147 | do | J. A. Johnson's spring | do | 2½ miles east of Pinelog | .48 |
| 36 | 147 | do | Oakhill Church Spring | do | do | 1.85 |
| 36 | 147 | June 26, 1899 | Hayse Spring | do | Folsom | .35 |
| 36 | 147 | do | Cedar Spring | do | Mostetters Mill, 1½ miles west of Folsom. | 4.45 |
| 36 | 147 | do | Trimble Spring | do | 2 miles north of Adairsville. | 2.35 |
| 36 | 147 | do | Gardners Spring | do | 5 miles north of Adairsville. | .41 |

*Miscellaneous records of the discharge of springs in papers not elsewhere listed*—Contd.

| Water-Supply Paper. | Pages on which data are given. | Date of measurement. | Name. | State. | Location. | Discharge. Sec.-ft. |
|---|---|---|---|---|---|---|
| 36 | 147 | June 26, 1899 | Blackwood Spring | Ga. | 5 miles southeast of Calhoun. | 1 |
| 37 | 277 | June 30, 1899 | Las Moras Spring | Tex. | Fort Clark, near Brackettville, and 10 miles from Spofford. | 60 |
| 37 | 277 | Dec. 24, 1895 | do | do | do | 21 |
| 37 | 277 | June 29, 1899 | San Felipe Springs | do | Below San Madre ditch diversion, near Del Rio. | 84 |
| 37 | 277 | do | San Madre Ditch | do | Near Del Rio | 29 |
| 39 | 434 | Aug. 21, 1899 | Pacoima submerged dam. | Cal. | (By pumping) | .24 |
| 39 | 440 | June 13, 1899 | Wooden Spring Branch. | Nebr. | Sec. 25, T. 35 N., R. 29 W. | 2.14 |
| 85 | 126 | Aug. 4, 1902 | Spring | Nev. | ¼ mile north of Heitman's house. | .74 |
| 85 | 126 | do | do | do | Near Heitman's house | .35 |
| 85 | 126 | Sept. 8, 1902 | do | do | do | .27 |
| 85 | 126 | Aug. 4, 1902 | do | do | South of Heitman's house. | 1.08 |
| 85 | 126 | Sept. 8, 1902 | do | do | do | 1.06 |
| 85 | 126 | Aug. 4, 1902 | do | do | Heitman's | 2.39 |
| 85 | 126 | Sept. 8, 1902 | do | do | do | 2.35 |
| 85 | 216 | June 10 and 11, 1902. | Springs | Idaho | All springs flowing into Snake River, between Shoshone Falls and the Cedars. | 112 |
| 98 | 293 | July 20, 1903 | Big Springs | Ala. | Tuscumbia | 177 |
| 127 | 120 | Apr. 19, 1904 | do | Ga. | ½ mile from left bank Flint River, about 4 miles down-stream from Albany. | 135 |
| 127 | 120 | Sept. 23, 1904 | do | do | do | 44 |
| 127 | 120 | Nov. 16, 1904 | do | do | do | 26.4 |
| 127 | 175 | Jan. 21, 1904 | Cave Spring | do | Cave Spring | 5.3 |
| 130 | 192 | Sept. 11, 1904 | Giant Springs | Mont. | Great Falls | 202 |
| 133 | 358 | Aug. 31, 1904 | Heitman's springs | Nev. | Mouth of Canyon | 1.2 |
| 133 | 358 | do | Monfrena Springs | do | do | 1.2 |
| 133 | 364 | Oct. 4, 1904 | Big Spring | Utah | Tributary to Rock Creek, in Duchesne River basin. | 7.4 |
| 135 | 271 | Aug. 10, 1904 | Hawley Springs | Idaho | ¼ mile below Heise post office. | .8 |
| 135 | 272 | Aug. 17, 1904 | Thurman Springs | do | North Fork of Snake River above Marysville. | .2 |
| 135 | 272 | do | West Bald Cabin Springs. | do | do | .2 |
| 135 | 272 | do | East Bald Cabin Springs. | do | do | 1.5 |
| 135 | 272 | do | Green Springs | do | do | .6 |
| 135 | 272 | Aug. 18, 1904 | Blue Springs | do | do | 3.6 |
| 135 | 272 | do | Grizzly Spring | do | do | 5.3 |
| 135 | 272 | Aug. 20, 1904 | Caldwell Spring No. 1 | do | do | .5 |
| 135 | 272 | do | Caldwell Spring No. 2 | do | do | .3 |
| 135 | 272 | Aug. 22, 1904 | Sorenson Spring | do | do | .8 |
| 135 | 273 | Aug. 23, 1904 | Bear or Little Spring | do | East bank of Henry Fork of North Fork of Snake River. | .5 |
| 135 | 273 | do | Thompson Springs | do | do | 5 |
| 135 | 273 | do | Garner Spring | do | do | .9 |
| 135 | 273 | Aug. 25, 1904 | Whitman Spring | do | Tributaries of Henry Lake. | 1.7 |
| 135 | 273 | do | Rock Springs | do | do | .7 |
| 135 | 273 | do | Sherwood Springs | do | do | 1.2 |
| 135 | 273 | do | Big Spring | do | do | 1.2 |
| 135 | 273 | do | Golf Spring | do | do | .7 |
| 168 | 98 | Apr. 26, 1905 | Blue Spring | Ga. | 4 miles from Albany on road to Hardaway. | 69 |
| 168 | 101 | Mar. 10, 1905 | Warm Springs | do | ½ mile from Warm Springs station. | 3.2 |
| 168 | 101 | Apr. 20, 1905 | do | do | do | 1.47 |
| 168 | 101 | do | do | do | do | 1.48 |
| 177 | 85 | Dec. 4, 1905 | Fish Springs | Cal. | Near Big Pine | 29 |
| 177 | 245 | Aug. 29, 1905 | Little Shasta Springs | do | Little Shasta | 20 |
| 197 | 241 | Mar. 10, 1905 | Warm Springs | Ga. | ½ mile from Warm Springs railroad station. | 3.2 |
| 197 | 241 | Apr. 20, 1905 | do | do | do | 1.47 |
| 197 | 241 | do | Warm Springs | Ga. | do | 1.48 |
| 197 | 302 | Jan. 21, 1904 | Cave Spring | do | Cave Spring | 5.3 |
| 212 | 92 | July 11, 1906 | A. Bayter's dug well and springs. | Utah |  | .11 |
| 212 | 92 | July 12, 1906 | N. Green's spring | do | Near fence No. 48 | .25 |

*Miscellaneous records of the discharge of springs in papers not elsewhere listed*—Contd.

| Water-Supply Paper. | Pages on which data are given. | Date of measurement. | Name. | State. | Location. | Discharge. Sec.-ft. |
|---|---|---|---|---|---|---|
| 212 | 92 | July 13, 1906 | Gillie's springs | Utah | SE. ¼ sec. 4, T. 29 S., R. 7 W. | 0.82 |
| 212 | 92 | do | 2 springs | do | Hannah Gale's farm | 1.35 |
| 212 | 92 | do | do | do | O. W. Gale's pasture | .68 |
| 212 | 92 | July 14, 1906 | Farnsworth & Bastian Bros. spring. | do | On Indian Creek | .11 |
| 212 | 92 | July 20, 1906 | Jeddy Dean's dug well | do | Beaver City | .25 |
| 212 | 92 | do | J. H. Cartwright spring | do | do | .05 |
| 212 | 92 | do | 2 springs of W. E. Yardley. | do | do | .23 |
| 212 | 92 | do | Jos. Jackson's 2 springs | do | South Beaver | .37 |
| 212 | 92 | Aug. 21, 1906 | Datson's warm springs | do | 1 mile east of Minersville | .13 |
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| 230 | 160 | May 7, 1902 | Paxton Spring | Nebr | Sec. 19, T. 15 N., R. 27 W. | .8 |
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| 247 | 118 | do | Buffalo Spring | do | do | 6.1 |
| 250 | 143 | Aug. 31, 1907 | Roaring Springs | Oreg | Southwest base of Steens Mountain. | 5 |
| 252 | 284 | Aug. 6, 1907 | Spring | do | Chris. Dennaen's, sec. 2, T. 25 S., R. 36 E. | 4 |
| 271 | 242 | Oct. 1, 1909 | Beetle's rest spring | do | Klamath Agency sawmill. | 24 |
| 288 | 135 | Dec. —, 1910 | Hancock Spring | Tex | Lampasas | 7.4 |
| 288 | 135 | do | Hanna Spring | do | do | .9 |
| 288 | 135 | Aug. —, 1910 | Barton Springs | do | Austin | 19 |
| 289 | 220 | Sept. 6, 1910 | Artesian well | Nev | Las Vegas | .43 |
| 289 | 220 | do | Every (?) | do | do | 1.56 |
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| 298 | 390 | June 12, 1905 | do | do | do | 50 |
| 298 | 390 | July 8, 1905 | do | do | do | 99 |
| 298 | 390 | Aug. 5, 1905 | do | do | do | 84 |
| 298 | 390 | Sept. 2, 1905 | do | do | do | 89 |
| 298 | 390 | Oct. 18, 1905 | do | do | do | 90 |
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| 298 | 390 | June 21, 1906 | do | do | do | 122 |
| 298 | 390 | Aug. 3, 1906 | do | do | do | 94 |
| 310 | 196 | Apr. 20, 1911 | Roaring Springs | Oreg | Sec. 6, T. 34 S., R. 32 E., in Catlow Valley. (?) | 6.05 |
| 310 | 196 | Aug. 14, 1911 | Threemile Springs | do | ½ mile below head of Threemile Creek in Catlow Valley. | .8 |
| 310 | 196 | Apr. 13, 1911 | Thompson Springs | do (?) | Tumtum Lake Basin near Denio-Andrews stage road. | .28 |
| 310 | 196 | Apr. 11, 1911 | Knox Springs | do | Sec. 22, T. 31 S., R. 32½ E., in Harney Valley. (?) | 1.5 |
| 314 | 81 | Aug. 28, 1909 | Spring | Alaska | Fish River Basin, Seward Peninsula. | 6.4 |
| 314 | 173 | July 10, 1907 | do | do | Grand Central River Basin, Seward Peninsula. | 3.8 |
| 326 | 364 | July 5, 1912 | Buckholz Springs | Mont | SE. ¼ SW. ¼ sec. 28, T. 21 N., R. 7 W., near Augusta. | 1.1 |
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| 332 | 275 | Mar. 31, 1911 | Drumheller Springs | Wash | Crab Creek drainage basin | 20 |
| 332 | 275 | Jan. 18, 1912 | do | do | do | 20.6 |
| 332 | 275 | Mar. 16, 1912 | do | do | do | 17.8 |
| 359 | 255 | Mar. 12, 1912 | Hunts Spring | Utah | Central | 3.0 |
| 360 | 285 | Aug. 21, 1913 | Warm Creek Spring | do | Near Fayette | 3.9 |
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| 360 | 286 | Aug. 16, 1913 | Preston Big Spring | Nev | Near Preston | 7.6 |
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| 360 | 286 | do | Spring No. 2 | do | 200 feet west and 150 feet north of Preston post office. | 3.7 |
| 360 | 286 | do | Spring No. 3 | do | 500 feet north of Preston post office. | 2.8 |
| 360 | 286 | Aug. 23, 1913 | Warm Springs | Oreg | Bridge at "OO" Ranch, Harney Lake Basin—main channel only. | 20.9 |
| 362 | 749 | July 1, 1913 | Intermittent spring | Wash | SW. ¼ sec. 13, T. 5 N., R. 10 E. | 49.7 |
| 370 | 808 | Aug. 6, 1907 | Spring | Oreg | Chris. Dennaen's, sec. 2, T. 25 S., R. 36 E. | 4 |
| 370 | 811 | May 7, 906 | Minnehaha Spring | do | Near Hermiston. | 2.6 |
| 370 | 811 | Sept. 27, 1905 | Cold Springs | do | do | 1.6 |
| 370 | 811 | Oct. 6, 1905 | do | do | do | 1.5 |

*Miscellaneous records of the discharge of springs in papers not elsewhere listed*—Contd.

| Water-Supply Paper. | Pages on which data are given. | Date of measurement. | Name. | State. | Location. | Discharge. |
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| | | | | | | *Sec.-ft.* |
| 370 | 811 | Oct. 2, 1905 | Gillette Springs | Oreg | Near Echo | 2 |
| 370 | 817 | Sept. 20, 1908 | Anna Creek Spring | do | Arants | 2.7 |
| 370 | 818 | Aug. 7, 1907 | Beetles Rest Spring | do | ½ mile north of Klamath Agency. | 25 |
| 370 | 818 | Mar. 23, 1908 | do | do | do | 26 |
| 370 | 818 | Apr. 27, 1908 | do | do | do | 25 |
| 370 | 818 | Oct. 1, 1909 | do | do | do | 24 |
| 370 | 818 | May 8, 1910 | Barclay Springs | do | Upper Klamath Lake Basin. | 1.7 |
| 370 | 820 | May 16, 1908 | Olene Springs | do | Near Olene | 2.9 |
| 370 | 821 | Aug. 31, 1907 | Roaring Springs | do | Southwest side of Steens Mountain. | 5 |
| 389 | 191 | Apr. 26, 1914 | Toquerville Springs | Utah | East side of Ash Creek, just above Toquerville. | 1 |
| 389 | 191 | Feb. 12, 1914 | Hunts Spring | do | Hunt's ranch, 1 mile southeast of Central. | 3.2 |
| 389 | 191 | Apr. 27, 1914 | do | do | do | 3 |
| 389 | 191 | Dec. 11, 1913 | Stone Cabin Spring | Nev | 7 miles northwest of Noapa. | 2 |
| 389 | 191 | May 23, 1914 | do | do | do | 1.8 |
| 389 | 191 | July 17, 1914 | do | do | do | 1.8 |
| 389 | 191 | Aug. 7, 1914 | do | do | do | 1.8 |
| 389 | 191 | Aug. 26, 1914 | do | do | do | 1.8 |
| 389 | 192 | Sept. 23, 1913 | Ash Meadow Springs | do | Near Amargosa | 3.4 |
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| 390 | 297 | July 23, 1914 | do | do | do | 7.7 |
| 390 | 297 | Aug. 28, 1914 | do | do | do | 4.7 |
| 390 | 297 | June 21, 1914 | Lower Mollen Springs | do | do | 6.8 |
| 390 | 297 | Aug. 28, 1914 | do | do | do | 7.6 |
| 390 | 297 | Oct. 16, 1913 | Preston Big Spring | Nev | Preston | 7.6 |
| 390 | 297 | do | Spring | do | 200 feet northwest of Preston post office. | 3.6 |
| 390 | 297 | do | do | do | Near Gee's at Preston | 2 |
| 390 | 298 | July 14, 1914 | Parsnip Springs | Oreg | At mouth of Camas Creek | 1.3 |
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| 391 | 328 | Aug. 27, 1914 | Roger Spring | do | ¾ mile above mouth of Sycan River. | 5 |
| 393 | 241 | Mar. 24, 1914 | Warm Springs | Idaho | Near Henry | .6 |
| 393 | 241 | Apr. 17, 1914 | do | do | do | 1 |
| 393 | 241 | May 2, 1914 | do | do | do | 1.2 |
| 393 | 241 | June 26, 1914 | do | do | do | 1.4 |
| 393 | 241 | Aug. 6, 1914 | do | do | do | 1.1 |
| 394 | 173 | Aug. 15, 1914 | Springs | Oreg | Tributary to Deschutes River between Spring River and West's bridge. | 13.5 |
| 394 | 173 | Aug. 14, 1914 | do | do | Tributary to Deschutes River between West's bridge and Benham Falls. | 28.4 |
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The following abbreviations are used in the index:

W, Water-supply paper (pp. 5–29).
A, Annual report (pp. 29–32).
M, Monograph (pp. 32–33).
P, Professional paper (pp. 33–34).
B, Bulletin (pp. 34–40).
MR, Report on mineral resources (p. 42).
GF, Geologic folio (pp. 43–45).
S, Cooperative report not published by the United States Geological Survey (pp. 45–47).

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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

**Water-Supply Paper 428**

# ARTESIAN WATERS IN THE VICINITY OF THE BLACK HILLS, SOUTH DAKOTA

BY

N. H. DARTON

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# ARTESIAN WATERS IN THE VICINITY OF THE BLACK HILLS, SOUTH DAKOTA.

By N. H. Darton.

## INTRODUCTION.

The foothills and plains adjoining the Black Hills in western South Dakota are semiarid and have been greatly retarded in development by the scarcity of water. Surface waters are meager in volume and at most places are considerably mineralized. Springs are rare, and as much of the area is underlain by clay or shale, the water from most shallow wells is unsatisfactory in quantity and quality. Several streams rising in or beyond the Black Hills cross the plains, but their flow and quality are variable. Fortunately the area is underlain by sandstones which receive water at their outcrops in the Black Hills and will yield it when tapped by wells, thus adding greatly to the resources of the region. To make the best use of these water-bearing beds a knowledge of the general geology of the region is necessary.

## GEOLOGY OF THE REGION.[1]

### GENERAL STRUCTURE AND STRATIGRAPHY.

The Black Hills uplift is an irregular dome or arch 125 miles long and 60 miles wide, whose longer dimension lies nearly northwest and southeast. It has brought above the general level of the Great

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[1] For a detailed account of the geology of the Black Hills, see Darton, N. H., Geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, 1905; Darton, N. H., Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 4, pp. 489–599, 1901; Jaggar T. A., jr., The laccoliths of the Black Hills: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 3, pp. 163–303, 1901; Darton, N. H., U. S. Geol. Survey Geol. Atlas, Oelrichs folio (No. 85), 1902; Darton, N. H., idem, Newcastle folio (No. 107), 1904; Darton, N. H., and Smith, W. S. T., idem, Edgemont folio (No. 108), 1904; Darton, N. H., idem, Sundance folio (No. 127), 1905; Darton, N. H., and O'Harra, C. C., idem, Aladdin folio (No. 128), 1905; Darton, N. H., and O'Harra, C. C., idem, Devils Tower folio (No. 150), 1907; Darton, N. H., and O'Harra, C. C., idem, Belle Fourche folio (No. 164) 1909; Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, 1909.

Plains a mass of pre-Cambrian crystalline rocks, about which is upturned a nearly complete sequence of sedimentary formations that range in age from late Cambrian to late Cretaceous and that dip away from the central nucleus. It is also partly encircled by extensive overlaps of the Tertiary deposits, which constitute the surface of much of the adjoining plains.

The region affords great opportunity for the study of stratigraphic relations and variations. Many of the rocks are hard, and they are extensively exhibited in the walls of canyons and gorges cut by streams that flow from the central hills. The structure along the sides of the uplift is that of a monocline dipping toward the plains. The oldest sedimentary rocks constitute an escarpment facing the crystalline-rock area, and each stratum passes beneath a younger in regular succession outward toward the margin of the uplift. (See Pl. X, p. 26.) The sedimentary members consist of thick sheets of sandstone, limestone, and shale, all of which (except the overlapping Tertiary deposits, which extend across the edges of the older formations) are essentially conformable. The stratigraphy is in many respects similar to that in the Rocky Mountains of Colorado and of Wyoming, but it possesses numerous distinctive local features. The Silurian and Devonian and parts of the Cambrian, Ordovician, Carboniferous, Triassic, Jurassic, and Tertiary are absent. The following formations are exposed:

*Generalized geologic section in the Black Hills region in South Dakota.*

| Age. | | Formation. | Character. | Ordinary thickness. |
|---|---|---|---|---|
| Tertiary | Oligocene | White River group: | | *Feet.* |
| | | Brule clay | Light-colored clay, fuller's earth, and sand. | 200 |
| | | Chadron formation. | Sand, clay, sandstone, conglomerate, and limestone. | 100 |
| Cretaceous | Upper Cretaceous. | Pierre shale | Dark-gray shale | 1,200 |
| | | Niobrara formation. | Chalk and calcareous shale | 175–225 |
| | | Carlile shale | Gray shales with thin sandstones, limestones, and concretions. | 500–600 |
| | | Greenhorn limestone. | Impure slabby limestone | 65 |
| | | Graneros shale | Dark shale with some lenses of massive sandstone in its lower part. | 900–1,150 |
| | | Dakota sandstone. | Massive buff sandstone | 20–200 |
| | Lower Cretaceous. | Fuson shale | Massive shales, white to purple, and very fine grained sandstone. | 30–150 |
| | | Minnewaste limestone. | Gray limestone | 0–30 |
| | | Lakota sandstone. | Massive buff sandstone, with some intercalated shale. | 100–300 |
| Cretaceous (?) | | Morrison shale | Massive shale, gray, greenish, and maroon. | 0–150 |
| Upper Jurassic | | Unkpapa sandstone. | Massive fine sandstone, white, purple, red, and buff. | 0–225 |
| | | Sundance formation. | Dark-gray shales and buff sandstones. | 100–300 |
| Triassic (?) | | Spearfish formation. | Red sandy shale with gypsum beds. | 550–695 |
| Carboniferous | Permian (?) | Minnekahta limestone. | Thin-bedded gray limestone | 30–50 |
| | | Opeche formation. | Red slabby sandstone and sandy shale. | 75–130 |
| | Pennsylvanian | Minnelusa sandstone. | Sandstones, locally buff and red, in greater part calcareous; some thin limestone included; red shale at base. | 400–500 |
| | Mississippian | Pahasapa limestone. | Massive gray limestone | 300–600 |
| | | Englewood limestone. | Pink slabby limestone | 30–50 |
| Ordovician | | Whitewood limestone. | Massive buff limestone | 0–80 |
| Cambrian | | Deadwood formation. | Red-brown sandstone and quartzite, locally conglomeratic, partly massive; much greenish-gray shale and limestone breccia in middle in northern hills. | 50–450 |

## THE FORMATIONS.

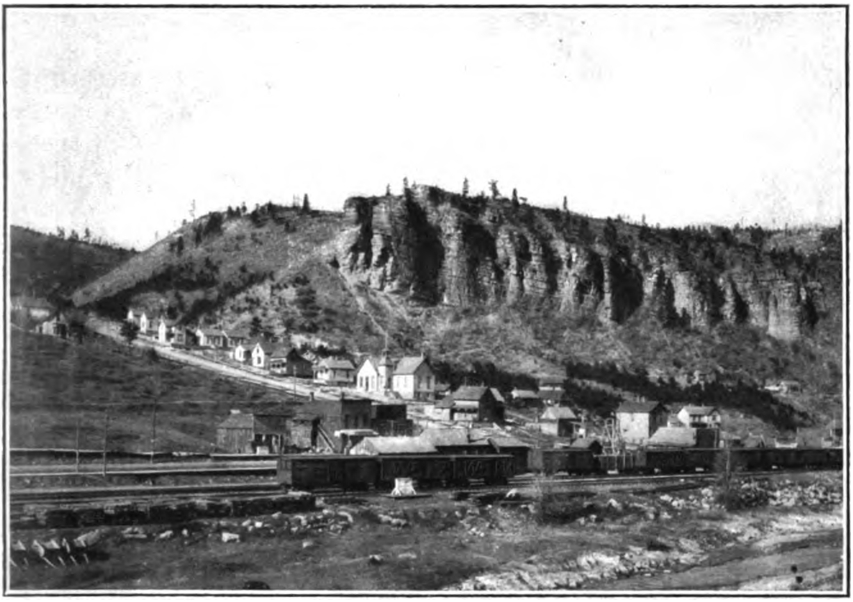
### DEADWOOD FORMATION.

The Deadwood sandstone encircles the Black Hills uplift and underlies a wide adjoining region but has been removed from the central area by erosion. The strata lie unconformably on the upturned edges of the pre-Cambrian schists, grits, and granites, on a surface that is relatively smooth except for shallow local channels. The formation is thick in the northern hills, attaining more than 400 feet in the Deadwood region, but it thins gradually to the south and especially to the southeast. For a short distance in the region west of Fairburn it consists of only 4 feet of coarse sandstone, but near Pringle and Wind Cave it is 50 to 60 feet thick. On Lightning Creek, west of Hill City and Custer, near Otis, and on Spring and French creeks it averages 100 feet. On Rapid and Squaw creeks it averages about 200 feet; on Elk and Little Elk creeks 250 feet; and near Galena and in Spearfish Canyon 450 feet.

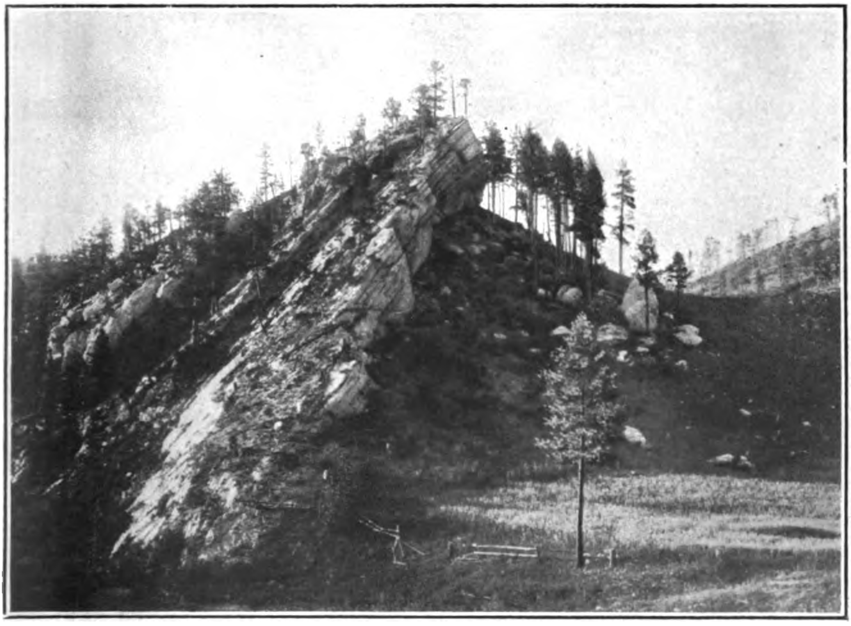
The materials are predominantly sandy and the color dark reddish brown or dirty buff. The basal member is ordinarily a hard massive reddish-brown sandstone or quartzite that contains pebbly layers. To the north, where the formation thickens, this member is overlain by thinner-bedded softer sandstones, in some places interbedded with more or less shale. Portions of the basal Deadwood beds are conglomeratic, ranging from those with a sprinkling of quartz pebbles in the sandstone to a very coarse heavy conglomerate made up of large rounded masses of crystalline rocks and vein quartz in a red-brown matrix.

Outcrops of the Deadwood sandstone range from a few rods to several miles in width but are generally narrow. For many miles they lie in the slope below the high escarpments of the Pahasapa limestone, where in places, particularly on the west side of the uplift, they are deeply buried under talus from the cliffs above. On the east side, where the dip is steeper, the hard quartzitic basal member forms prominent knobs or long bare rocky slopes. The many canyons cutting back into the western escarpment and those crossing the ridges on the east side of the uplift afford excellent exposures.

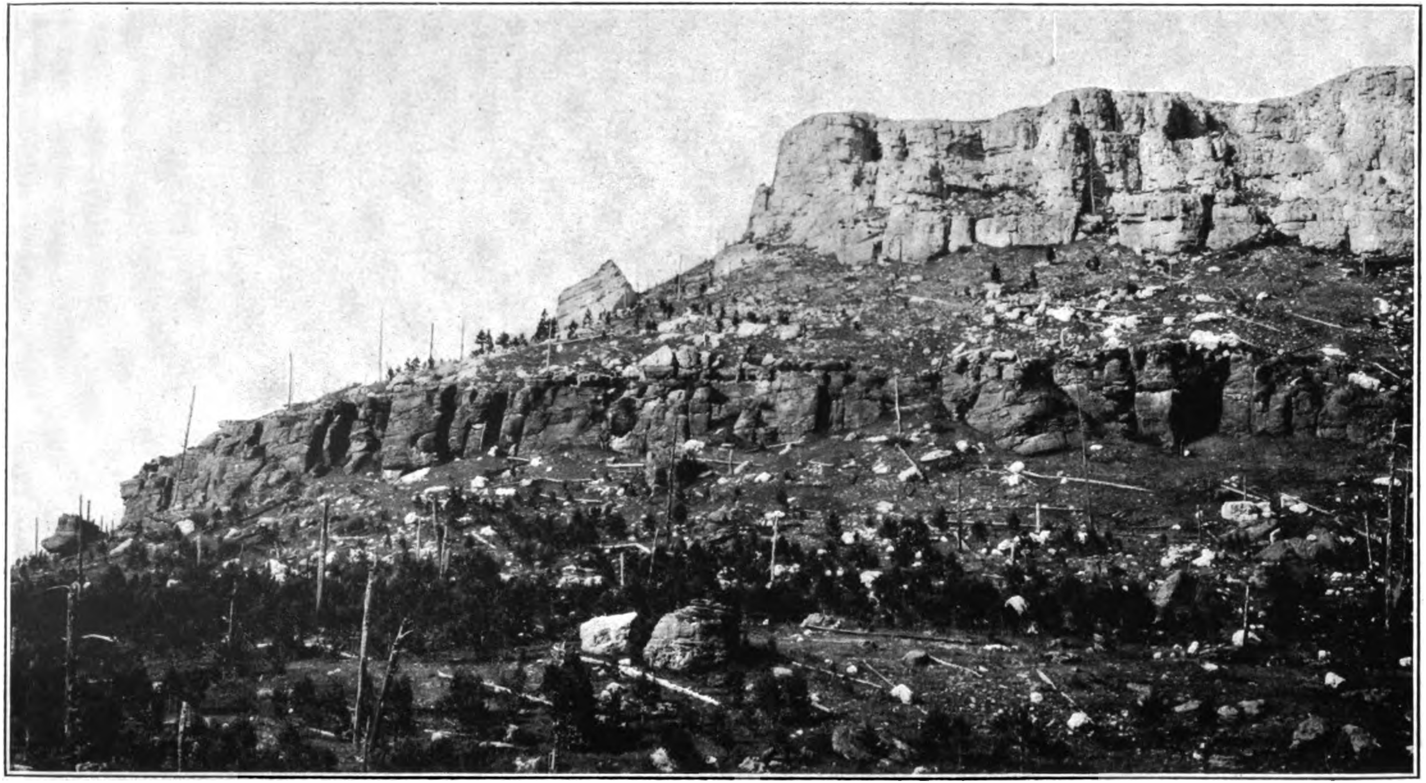
In the region about Deadwood and in a large part of the northern hills the formation comprises 1 to 30 feet of basal conglomerate, overlain by 30 feet of sandstone, in turn overlain by 200 to 300 feet of gray shales that carry layers of flaggy limestone, limestone conglomerate, and sandstone. Near the top is a very characteristic member of hard, massive sandstone 5 to 22 feet thick (see Pls. II and III), overlain by 20 to 45 feet of green shales. The limestone conglomerate layers consist of flat pebbles and flakes of limestone more or less thickly sprinkled with grains of glauconite.



*A.* UPPER SANDSTONE OF DEADWOOD FORMATION IN NORTHERN PART OF DEADWOOD, S. DAK., LOOKING NORTHEAST.



*B.* UPPER BED OF MINNELUSA SANDSTONE, BEAR BUTTE CANYON, WEST OF STURGIS, S. DAK., LOOKING NORTH.



UPPER SANDSTONE OF DEADWOOD FORMATION IN CANYON OF BOX ELDER CREEK, S. DAK.

Overlain by Englewood and Pahasapa limestones.

### WHITEWOOD LIMESTONE.

The Whitewood limestone is conspicuous in the northern Black Hills, particularly in Spearfish Canyon and about Deadwood, where it attains a thickness of 60 to 80 feet and crops out extensively in a number of canyons, a typical exposure appearing in Whitewood Canyon below Deadwood. It thins to the southeast and southwest and finally disappears west of Piedmont. The rock is a massive tough limestone of buff color with brownish spots or mottlings.

### ENGLEWOOD LIMESTONE.

The Englewood limestone consists of 30 to 60 feet of thin-bedded pale pinkish-buff limestones, which appear to extend continuously around the Black Hills, outcropping in the lower slopes of the limestone escarpment and in canyons, everywhere immediately beneath the Pahasapa limestone. It merges rather abruptly into the overlying Pahasapa, here and there with a few feet of impure buff limestone intervening. Generally it is sharply separated from the Deadwood formation or the Whitewood limestone by an abrupt change in the nature of the materials. It is usually fossiliferous, containing numerous corals and shells of earlier Mississippian age.

### PAHASAPA LIMESTONE.

The Pahasapa limestone is conspicuous in the Black Hills uplift, constituting much of the high, wide plateau west of the central crystalline rocks and being characteristically exhibited in the great lines of cliffs in the escarpment surrounding that region. It is a thick, massive gray limestone, usually outcropping either in precipitous cliffs, with many picturesque irregularities of form or in wide, flat surfaces. The formation has no noteworthy divisions, but in many places its upper part is siliceous and flinty and more or less stained red by the overlying basal red shale of the Minnelusa.

The most extensive exposures of the Pahasapa limestone are in the wide, high plateau west of Custer. Here the formation begins in a line of high cliffs surmounting slopes of crystalline schists and of relatively thinner sheets of Englewood limestone and Deadwood sandstone. In Pennington County the plateau shows a width of 10 miles of continuous limestone outcrop, constituting the most elevated area in the Black Hills, except the small summit of Harney Peak. To the west the limestone passes beneath the Minnelusa sandstone, but it is exposed again in the arch of the steep anticline near the Wyoming-South Dakota line. East of the area of crystalline rocks the limestone forms many conspicuous knobs or lies on the eastern slopes of ridges formed by the quartzite of the Deadwood formation, but it does not attain the high altitude which it has farther west. To the east the steeper dip carries the formation below the surface within a short distance, but it constitutes the walls of many of the canyons from Beaver Creek northward, notably the deep canyon of Spearfish Creek. In it are some extensive caverns, including Wind Cave, Jewel Cave, Crystal Cave, and Onyx Cave.

The thickness of the Pahasapa limestone in the central and southern Black Hills ranges from about 550 feet at the northwest to 300 feet at the east and southeast. Along the southeast side of the hills it measures 300 feet, with slight local variations; it increases to 550 feet or more on Elk Creek and to 600 feet on Bear Butte Creek; and it ranges from 300 to 400 feet in the Deadwood region. In Spearfish Canyon it is 630 feet, at Crow Peak 550 feet, and in the plateau northwest of Custer and Hill City, 500 feet. Fossils indicating lower Mississippian age occur sparingly in the formation.

### MINNELUSA SANDSTONE.

The Minnelusa sandstone extends around the Black Hills uplift in a broad zone of conspicuous exposures. The rocks are mainly thick masses of buff and reddish sandstones, mostly fine grained and massively bedded, which are striking features in the walls of many canyons. In their unweathered condition they contain considerable carbonate of lime. Thin sheets of limestone and of red and gray sandy shales occur in places. At the base is a red shale that contains thin beds of limestone. The formation is thickest on the west side of the uplift, where it attains 500 feet. It thins gradually to the south and east, being 405 feet thick south of Spearfish, 450 feet on Whitewood and Bear Butte creeks, 500 feet on Elk and Boxelder creeks, 400 feet on Rapid Creek, 460 feet on Spring Creek, and about 420 feet west of Hot Springs.

The Minnelusa sandstone does not give rise to very large topographic features but generally occupies extensive elevated slopes surmounted by low hills and ridges formed by its harder layers.

Breccias characterize its middle beds throughout the southern Black Hills. The brecciated material is usually somewhat more calcareous than the matrix, but it is all of local origin. In the region west of Hermosa and thence northward the Minnelusa consists of a thick coffee-colored sandstone (see Pl. II, *B*), underlain by a reddish-buff sandstone with some thin interbedded limestone layers, and this in turn by a basal member of gray sandstone, which lies on red shale that contains thin layers of limestone.

A few fossils found in the upper beds west of Hot Springs appear to indicate that the formation is of Pennsylvanian (upper Carboniferous) age.

### OPECHE FORMATION.

The red beds of the Opeche formation, which lies between the Minnelusa sandstone and the Minnekahta limestone, crop out continuously around the Black Hills, mostly in the slopes below the escarpments of Minnekahta limestone, with an average thickness of somewhat less than 100 feet. The materials are soft red sandstone and sandy shale, mainly thin bedded and containing variable amounts of clay admixture. The top of the formation, for the first few feet below the Minnekahta limestone, consists of shale, which is invariably deep purple. The basal beds of the formation usually consist of red sandstone in beds 4 to 15 inches thick.

On Spring, Battle, and French creeks the formation averages about 100 feet in thickness, and in Beaver Canyon it attains its maximum thickness of 140 feet. On Cold Brook, 4 miles northwest of Hot Springs, where it is 115 feet thick, it consists of the customary purple clay at the top, 50 feet of red sandy clay next below, and 60 feet of red sandstone at the bottom, in beds 1 to 4 feet thick with red-clay partings. Farther down Cold Brook, at a point 1½ miles from Hot Springs, a thickness of 135 feet is exhibited. On Rapid and Elk creeks it is 90 feet thick. Along the southwest side of the Black Hills the thickness averages from 70 to 90 feet, and on the northern slopes it is about 75 feet.

The age of the formation has not been definitely determined, for so far it has yielded no fossils. It has been assumed to be Permian.

### MINNEKAHTA LIMESTONE.

The Minnekahta limestone, long known as the "Purple limestone," is prominent in the Black Hills region. Though thin, averaging less than 50 feet, it is hard and covers moderately extensive areas on the outer slopes of the Minnelusa sandstone outcrop zone. The prominence of the Minnekahta limestone outcrop is due largely to the deep erosion of the soft red shale of the overlying Spearfish formation, which has left the limestone bare on slopes up which the red shale originally extended. As the underlying Opeche formation is also soft, the limestone nearly everywhere presents an escarpment, and the many canyons which are cut through it have vertical limestone walls. (See Pl. IV.) Its thickness is 45 feet on Rapid Creek, 40 feet on Elk, Bear Butte, and Battle creeks, and 30 feet on Whitewood, Spring, and Spearfish creeks.

The formation is uniform in character throughout, being a thin-bedded light-colored limestone containing magnesia and more or less clay. Its thin bedding is characteristic, although the thin layers are so cemented together that the outcropping ledges present a massive appearance. On weathering, however, it breaks into slabs, most of which are 2 to 3 inches thick. In general it is slightly pinkish, with a tinge of purple, from which the term "Purple limestone" originated. The Minnekahta limestone contains some fossils which are regarded as of probable Permian age, though they may be Triassic.

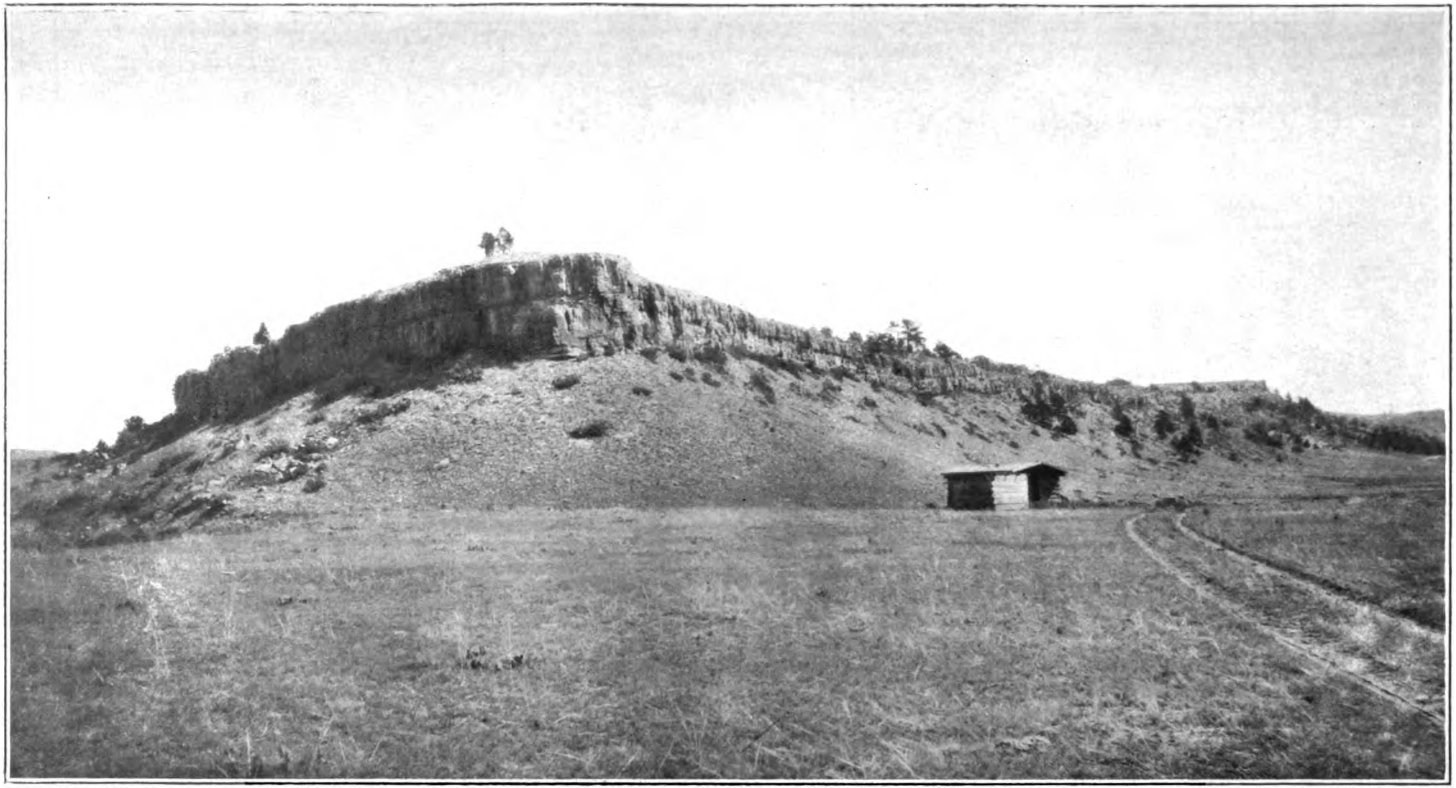
### SPEARFISH FORMATION.

The Spearfish formation is a conspicuous series of red beds with gypsum deposits that encircles the Black Hills, in most places giving rise to the wide Red Valley. This valley is treeless and for the most part consists of broad, bare red slopes and red buttes, with numerous outcrops of gypsum.

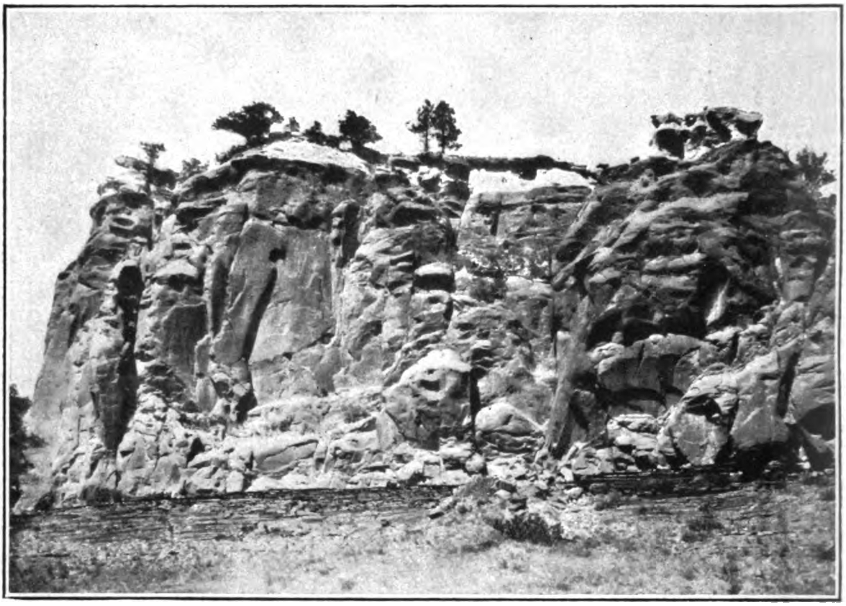
The formation consists of 550 to 695 feet of red sandy shale, with intercalated beds of gypsum in places 30 feet thick. The bright red of the shale and the snowy whiteness of the gypsum are striking features. Were it not for the beds of gypsum the formation would present no noticeable features of stratigraphy. The red shale contains different amounts of sand in different localities, and includes some soft, thin-bedded red sandstones. The gypsum occurs in beds, some of which extend continuously over wide areas. More or less gypsum of secondary deposition, in very small veins, is scattered through the formation.

The continuity of the outcrops of the red beds is considerably broken in the region west of Fairburn and Hermosa by overlaps of the White River deposits, which in some places completely fill the Red Valley. The width of the outcrop is 1 to 3 miles and attains a maximum in the region west of Buffalo Gap and in the broad belt extending from Minnekahta station nearly to the north end of Elk Mountain. Owing to the local steep dip of the formation, the outcrop is very narrow for 5 miles north from Cascade Springs.

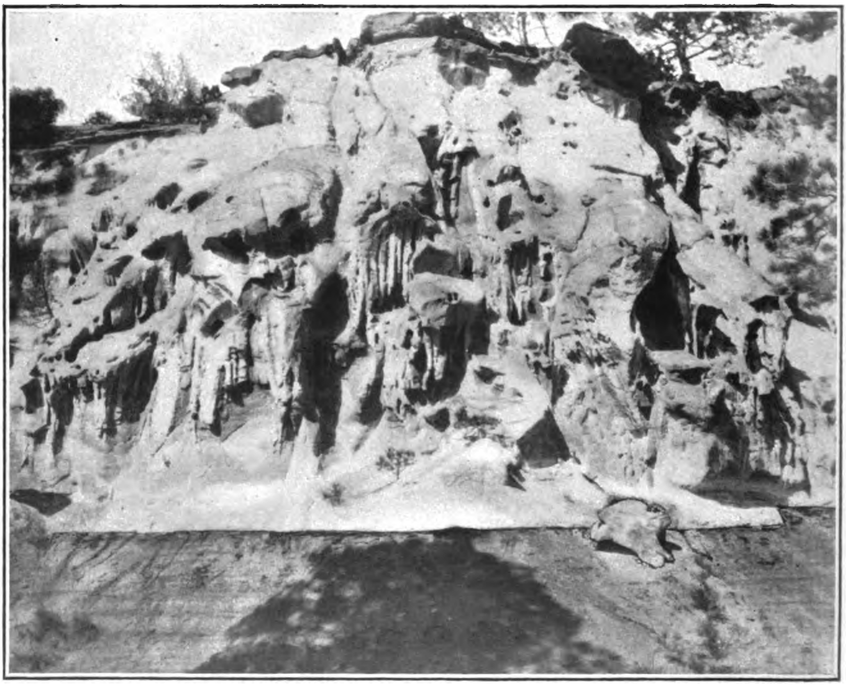
The thickness of the Spearfish formation can in few places be determined with any degree of accuracy, owing to the softness of its materials and the numerous variations in its dip. In the deep well at Fort Meade the formation is 695 feet thick and in the Edgemont wells about 600 feet. Along the east side of the Black Hills it appears to be 550 to 600 feet thick, so far as can be estimated from very indefinite observations of dip. In this region the principal bed of gypsum occurs about 100 feet above the base of the formation. West of Hermosa this gypsum bed has a thickness of about 15 feet, but toward the south, in the region west of Fairburn, it thins out and



TYPICAL CLIFF OF MINNEKAHTA LIMESTONE CAPPING RED SHALE OF OPECHE FORMATION.



*A.* EXPOSURE 6 MILES NORTH OF MINNEKAHTA, S. DAK.



*B.* EXPOSURE 7 MILES SOUTH OF HOT SPRINGS, S. DAK.

BASAL SANDSTONE OF SUNDANCE FORMATION.

may at some points be absent. Near Spearfish and Sturgis a thick bed of gypsum lies near the top of the formation and a thinner bed about 120 feet above the base. West of Buffalo Gap the gypsum deposits increase in thickness, and they attain a maximum at Hot Springs, where the principal beds have a thickness of 33½ feet, with a 10-foot parting of red shale between them. In the wide part of Red Valley, extending southward from Hot Springs to Sheps Canyon, gypsum beds are conspicuous, but they gradually diminish in thickness in that direction.

At Cascade Springs and thence northward on the west side of the anticline the dips are very steep, and the outcrop of the Spearfish formation becomes so narrow that the Red Valley is only a few rods in width from the springs northward nearly to the railroad. Here a measurement was made of the beds from the steep slopes of the Minnekahta limestone to the basal sandstone bed of the Sundance formation, 420 feet in all, but doubtless the strata are considerably squeezed in a steep fold of this sort. At the base of the Spearfish formation in this section is 150 feet of red sandy shales, above which is a bed of gypsum in places 20 feet in thickness, overlain by 250 feet of red sandy shales, with a few thin layers of gypsum.

Throughout the Black Hills the formation is distinctly separated from the underlying Minnekahta limestone and the overlying shales or red sandstone of the Sundance formation. It has been regarded as probably Triassic in age, because it lies unconformably beneath marine Jurassic deposits and is underlain by the Minnekahta limestone of supposed Permian age, but as yet it has yielded no determinable fossils.

### SUNDANCE FORMATION.

The outcrop of the Sundance formation extends continuously around the Black Hills uplift, mainly along the outer slope of the Red Valley, or the lower, inner slope of the hogback ridge. The formation comprises 225 to 300 feet of shales and sandstones, in a series that differs but little in sequence in different portions of the region. The succession includes 50 to 60 feet of lower dark shale, 30 feet of massive buff ripple-marked sandstone, 30 feet of reddish sandy shale, and at the top 100 to 200 feet of green shale that contains thin fossiliferous limestone layers. Some local variation occurs, especially in the massive red or buff basal sandstone, which in many places attains a thickness of 25 feet and lies on the somewhat irregular surface of the red shale of the Spearfish formation. (See Pl. V.) West of Fairburn the formation thins to less than 100 feet for a short distance. The abundant marine fossils are of later Jurassic age.

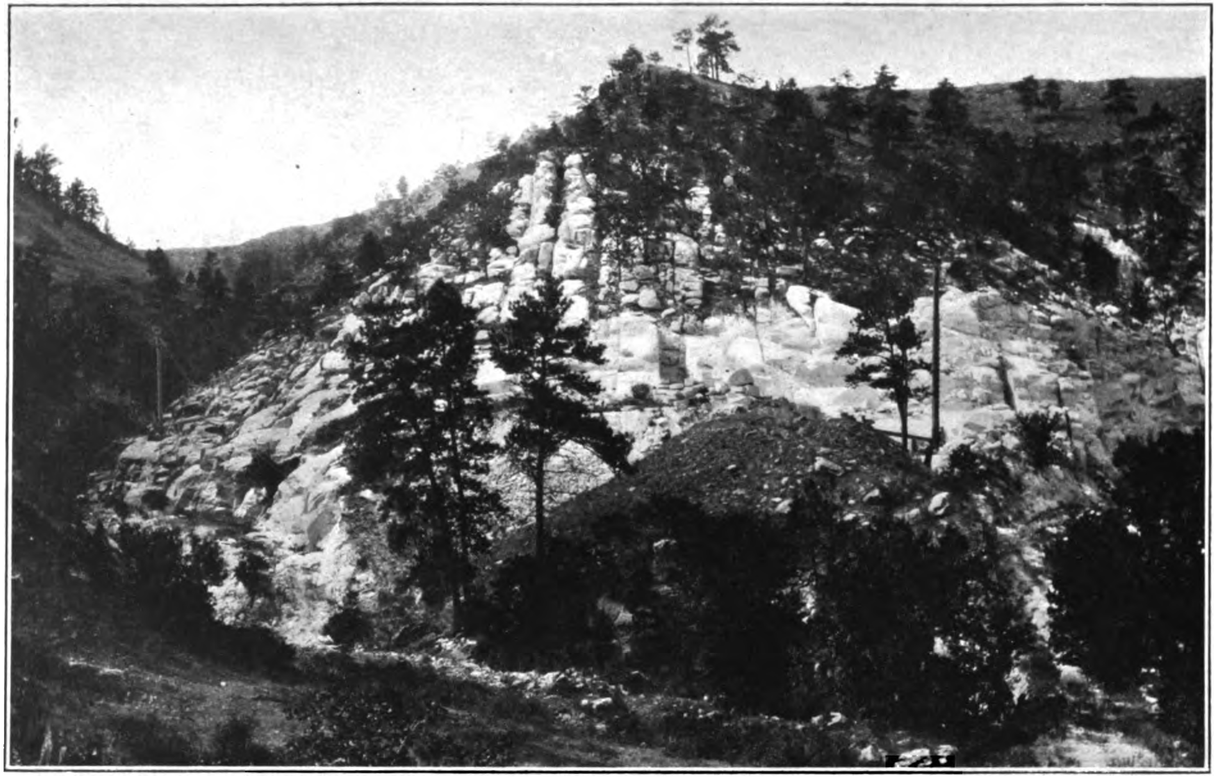
### UNKPAPA SANDSTONE.

The Unkpapa sandstone, the next overlying formation, is everywhere clearly separable both from the Sundance formatión below and the Morrison shale or the Lakota sandstone above. It is a very massive fine-grained sandstone, which ranges in color from white to purple and buff. Its greatest development is in the hogback ridge east of Hot Springs. Its first outcrops to the south are observed about Cascade Springs, from which it extends continuously past Hot Springs, along the east side of the Black Hills. It is thickest in Sheps Canyon, southeast of Hot Springs, where 225 feet was measured. From Buffalo Gap to French Creek it ranges from 125 to 150 feet, except near Dry Creek, where it is only 90 feet. From Spring Creek nearly to Rapid City it is 40 to 60 feet. At Rapid City it is 125 feet and north of Rapid City 140 feet, but it thins north of Blackhawk and is 40 feet near Piedmont and Tilford. From Sturgis north it is very thin and inconspicuous.

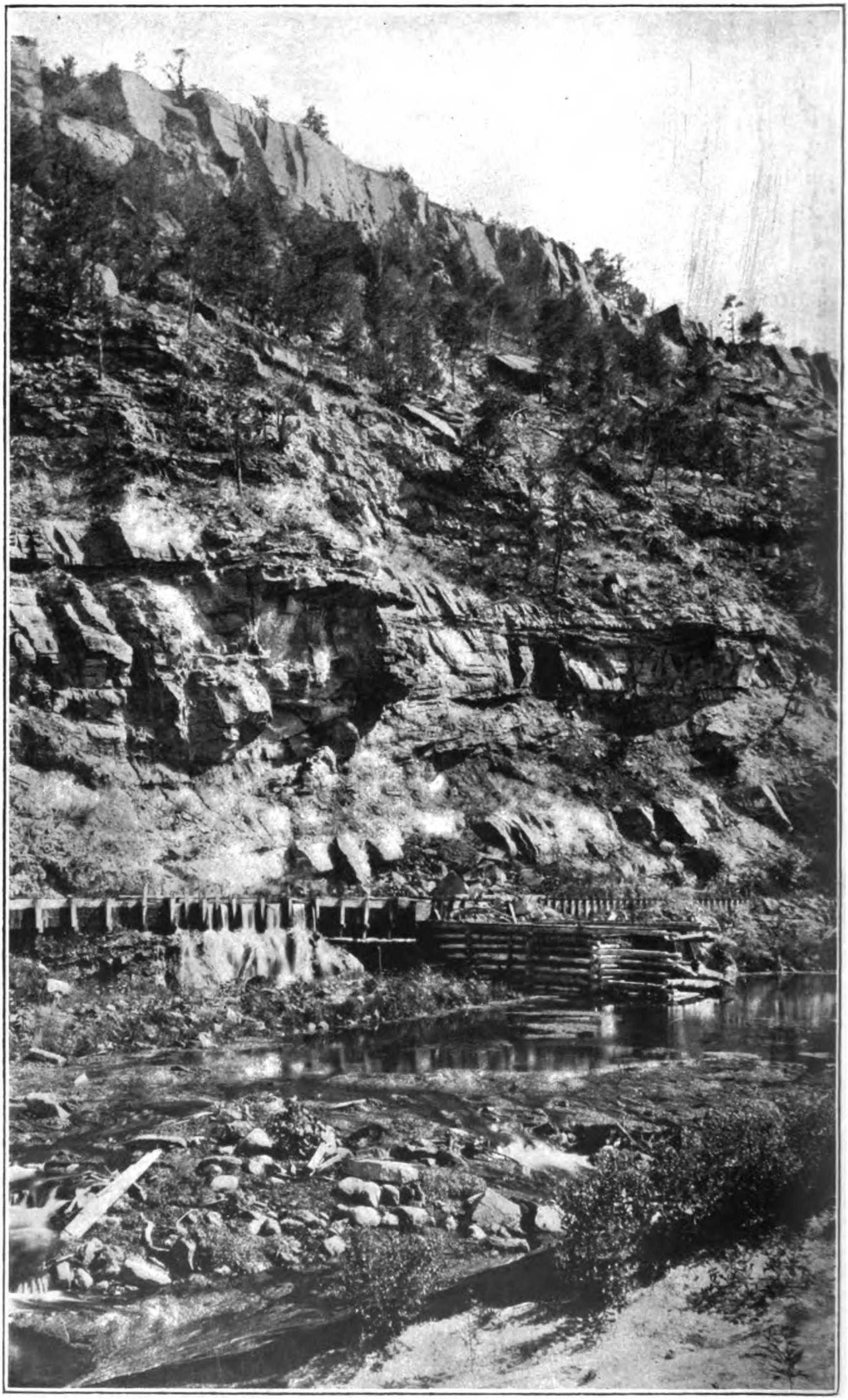
The coloring of some of the exposures east of Hot Springs is very striking, the rocks being brilliant in pink, purple, and pure white. (See Pl. VI.) Near Buffalo Gap, where the rock has been quarried to some extent for building stone, portions of it are beautifully banded in different colors, in part along the stratification planes but in places diagonal to them. In the quarry west of Buffalo Gap these banded beds exhibit most instructive minute faulting, affording fine illustrations of block-fault phenomena. Contacts with the overlying buff Lakota sandstone are exposed at many points and are marked by considerable erosional unconformity.

### MORRISON SHALE.

The outcrop of the Morrison shale extends along the upper and inner slopes of the hogback ridge, but is absent in the southeastern part of the uplift, from the vicinity of Hermosa to a point southwest of Hot Springs. Elsewhere the formation is generally from 75 to 150 feet thick and lies between the Unkpapa sandstone, or Sundance formation, and the Lakota sandstone. The maximum thickness observed was 220 feet in slopes 2 miles north of Piedmont. It ranges from 75 to 100 feet between Sturgis and Spearfish. The formation is composed mainly of "joint clay" or massive shale, somewhat darker and more fissile to the east than to the north and west. The predominating color is a very pale greenish gray, merging into chocolate and maroon. Thin beds of fine-grained white or light-gray sandstone and some thin local layers of impure limestone are included. A few fresh-water shells were observed, and there is an almost general occurrence of dinosaur bones, which are classed as Jurassic bv some paleontologists and as early Cretaceous by others.



UNKPAPA SANDSTONE IN ODEL CANYON NEAR HOT SPRINGS, S. DAK.



DAKOTA AND LAKOTA SANDSTONES IN CANYON OF FALL RIVER, S. DAK.

### LAKOTA SANDSTONE.

The Lakota sandstone constitutes the crest and upper slopes of the hogback ridge that forms the outer encircling rim of the Black Hills. Its beds are hard, coarse grained, cross-bedded, and massive, with partings of shale of no great thickness. Local deposits of coal occur in its base about Cambria, on Hay Creek, and east of Edgemont. In the central and southern Black Hills the thickness is usually 200 to 300 feet, though it differs locally; to the north it averages about 100 feet. Its maximum is about 480 feet in Fuson Gap. On French, Dry, and Squaw creeks it is about 300 feet, and in Elk Mountain and on Pass Creek 200 feet. The Lakota lies on the Morrison shale, except in the region from Hermosa to a point beyond Hot Springs, where it overlaps unconformably on the Unkpapa sandstone.

The Lakota sandstone shows numerous local variations in the thickness of the beds and in the occurrence of intercalated shales. In the canyon of Fall River, where the formation is 225 to 250 feet thick, the sandstones are very massive and are separated by several beds of greenish-gray shale 15 to 20 feet thick. (See Pl. VII.) The uppermost member, a dull-yellow sandstone, is overlain by the Minnewaste limestone in the region east of Hot Springs. The lower beds are conglomeratic at most localities.

Except petrified wood, which is abundant, few fossils have been found in the Lakota sandstone. A few bones of a stegosaur were obtained near Buffalo Gap; and remains of isopods, *Estheria*, fish, and crocodile were found 3 miles north of Piedmont. Plants of Lower Cretaceous age occur east of Hot Springs and in the Hay Creek region, and pine needles are abundant in some of the coaly layers. Cycads are found in places, notably in the slopes southwest of Minnekahta and near Blackhawk.

### MINNEWASTE LIMESTONE.

The Minnewaste limestone, a nearly pure light-gray limestone of uniform character throughout, overlies the Lakota sandstone from the vicinity of Cascade Springs northward to Buffalo Gap. For the greater part of its course it is only 25 feet thick, but it is conspicuous on the hogback ridges east of Hot Springs, extending far up some of the higher slopes. One of the most extensive exposures is on Cheyenne River 8 miles southeast of Hot Springs, where the water falls over a ledge of it about 20 feet high. Widespread outcrops may be seen in the anticline 2 miles east of Hot Springs, where the strata dips steeply to the west. It thins out rapidly north of Buffalo Gap and appears to be entirely absent in the canyon of Fuson Creek. It is thin at Cascade Springs and disappears a short distance to the west.

An extended search has failed to detect any fossils in it, but it is of Lower Cretaceous age, as it lies below the Fuson shale.

### FUSON SHALE.

The Fuson shale consists of fine-grained deposits lying between the Dakota and the Lakota sandstones and encircling the Black Hills. Its average thickness is about 65 feet, but it varies considerably and in general is thickest in the northern hills, although it is nearly 150 feet thick in Buffalo Gap. It is 100 feet thick southeast of Cascade Springs, but it thins westward to 30 to 60 feet and measures less than 50 feet in the Pass Creek region. It consists principally of a mixture of clay and fine sand and partly of fire clay, as a rule massively bedded. Some beds of sandstone are locally included. Its predominant color is white or gray, but in many places buff, purple, and maroon tints are conspicuous.

As the formation is relatively soft compared with adjoining sandstones, it usually forms a depression between a low crest of Dakota sandstone on the one hand and the higher summits of the Lakota sandstone on the other. Locally it is covered by talus from the sandstone cliffs above. One of its most extensive exposures is at the falls of Cheyenne River, where the section is as follows:

*Section of Fuson shale at falls of Cheyenne River, south of Hot Springs.*

| | Feet. |
|---|---|
| Dakota sandstone. | |
| Dark sandy shale | 4 |
| Soft gray slabby sandstone; plants | 6 |
| Compact white mudstone | 8 |
| Dark-green clay | 1 |
| Dark-gray compact mudstone | 25 |
| Very compact white mudstone | 2½ |
| Gray mudstone | 6 |
| Harder white mudstone | 9 |
| Purplish shale | 1 |
| White fine-grained sandstone | 5–12 |
| Purple shale | 6–8 |
| Light-buff massive sandstone | 25 |
| Dark-buff coarser sandstone, much honeycombed by weathering | 25 |

The formation is considerably obscured by talus along the canyon of Fall River but outcrops extensively in the side canyons, notably in one on the steep side of the anticline 2 miles due east of Hot Springs, where much of the material is bright purple and strongly resembles a shale that has been subjected to heat. Fuson Canyon affords some striking exposures of a portion of the formation in cliffs capped by Dakota sandstone. The uppermost bed is a moderately hard sandstone underlain by 10 feet of purplish-gray shales.

10 feet of white mudstone, and 20 feet of bright-purple shale. On Dry Creek the formation is represented by 50 feet of white massive shale. On Squaw Creek the Lakota sandstone is overlain by about 50 feet of buff and purple shale, grading upward to the Dakota sandstone through several feet of shale and thin sandstone. Northwest of Hermosa shales of bright color prevail, much of the material being purple. Near Rapid City the formation is 100 feet thick, and near Sturgis 65 feet, but a few miles north of Sturgis it thickens to 100 feet or more and consists of white sandy beds of considerable hardness. On the south and north sides of the hills the formation is at many places mixed with considerable sand and sandstone. In the Hay Creek region it has yielded large numbers of fossil plants of Lower Cretaceous age.

### DAKOTA SANDSTONE.

The formation here designated the Dakota sandstone is the uppermost member of the tripartite series formerly designated "Dakota sandstone" in the Black Hills region. It extends continuously around the uplift, but being rarely more than 100 feet thick it constitutes only a small part of the hogback ridge. Nevertheless it is conspicuous, because the foothills to which it usually gives rise slope steeply out of the adjoining valley or level plain formed by the Graneros shale. It consists mostly of gray sandstone, weathering brown, which is hard and massive below but thinner bedded above. South of Fairburn it is 150 to 200 feet thick and at Buffalo Gap 200 feet. (See Pl. VIII.) North of Edgemont it is in few places more than 150 feet thick. From Squaw Creek northward the sandstone thins to less than 50 feet at most places, and locally, south of Fort Meade, to less than 20 feet. Near Whitewood it is 50 to 60 feet thick and on Pass Creek 150 feet thick. The fossil impressions of dicotyledonous leaves obtained from it are regarded as Upper Cretaceous in age.

### GRANEROS SHALE.

The Graneros shale, the lowest formation of the Colorado group of early Benton age, extends entirely around the Black Hills uplift and is marked by lowlands and valleys. It consists of dark fissile shale 900 to 1,150 feet thick, the maximum being north of Belle Fourche and east of Sturgis. From Edgemont to Rapid City the average thickness is 900 feet.

In some areas the formation contains, toward its base, a thin layer of hard sandstone, which rises in a ridge of considerable prominence near Rapid City, Hermosa, Newcastle, and Belle Fourche. It occurs locally, but apparently at the same horizon, 150 to 300 feet above the Dakota sandstone. Its maximum thickness is about 30 feet. At Hermosa, where it is traceable for 4 to 5 miles, it is about 200 feet above the base of the formation and attains a thickness of 15 feet. At Rapid City and southeast of Sturgis it is again conspicuous 275 feet above the base of the formation. Near Belle Fourche it is thin, soft, and in places absent.

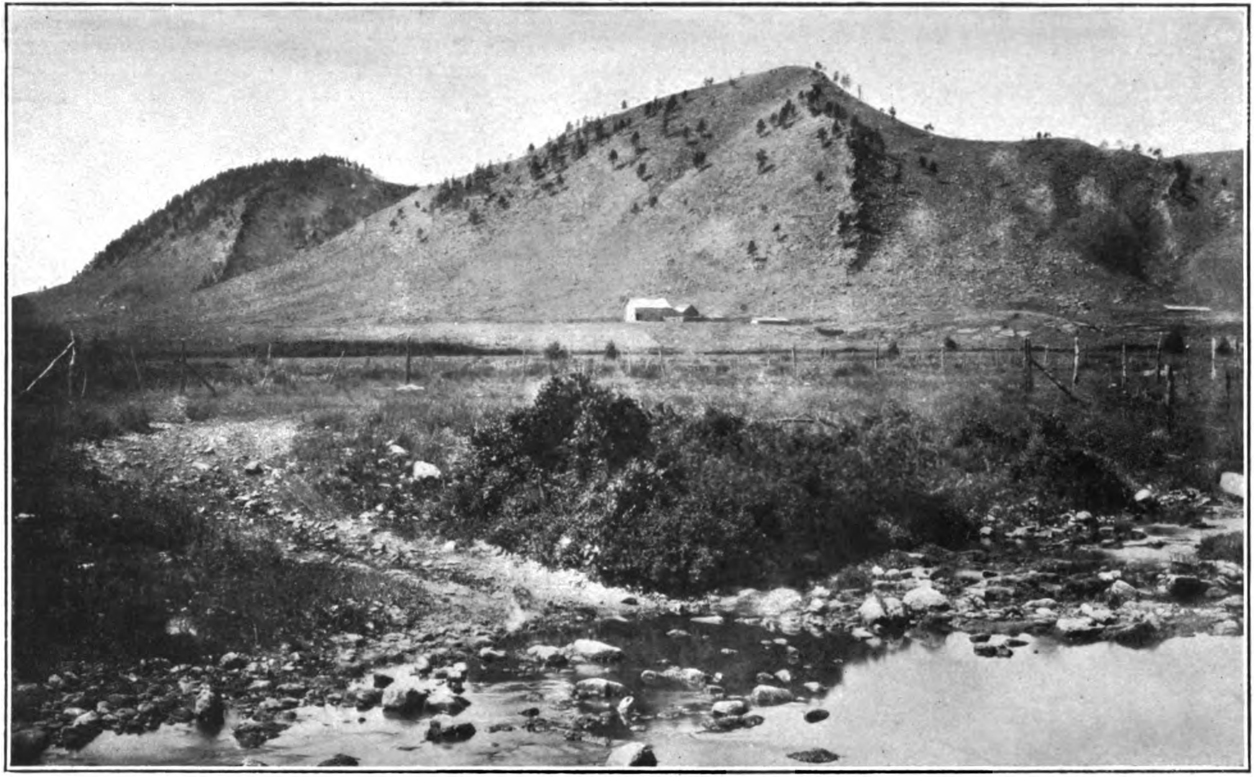
Next above this sandstone horizon is a series of hard gray shales known as the Mowry shale member. It is 150 to 200 feet thick and owing to its hardness gives rise to ridges of moderate prominence, many of which bear scattered pine trees. The shales of this member contain large numbers of fish scales and weather to a light silvery color, both characteristic features.

### GREENHORN LIMESTONE.

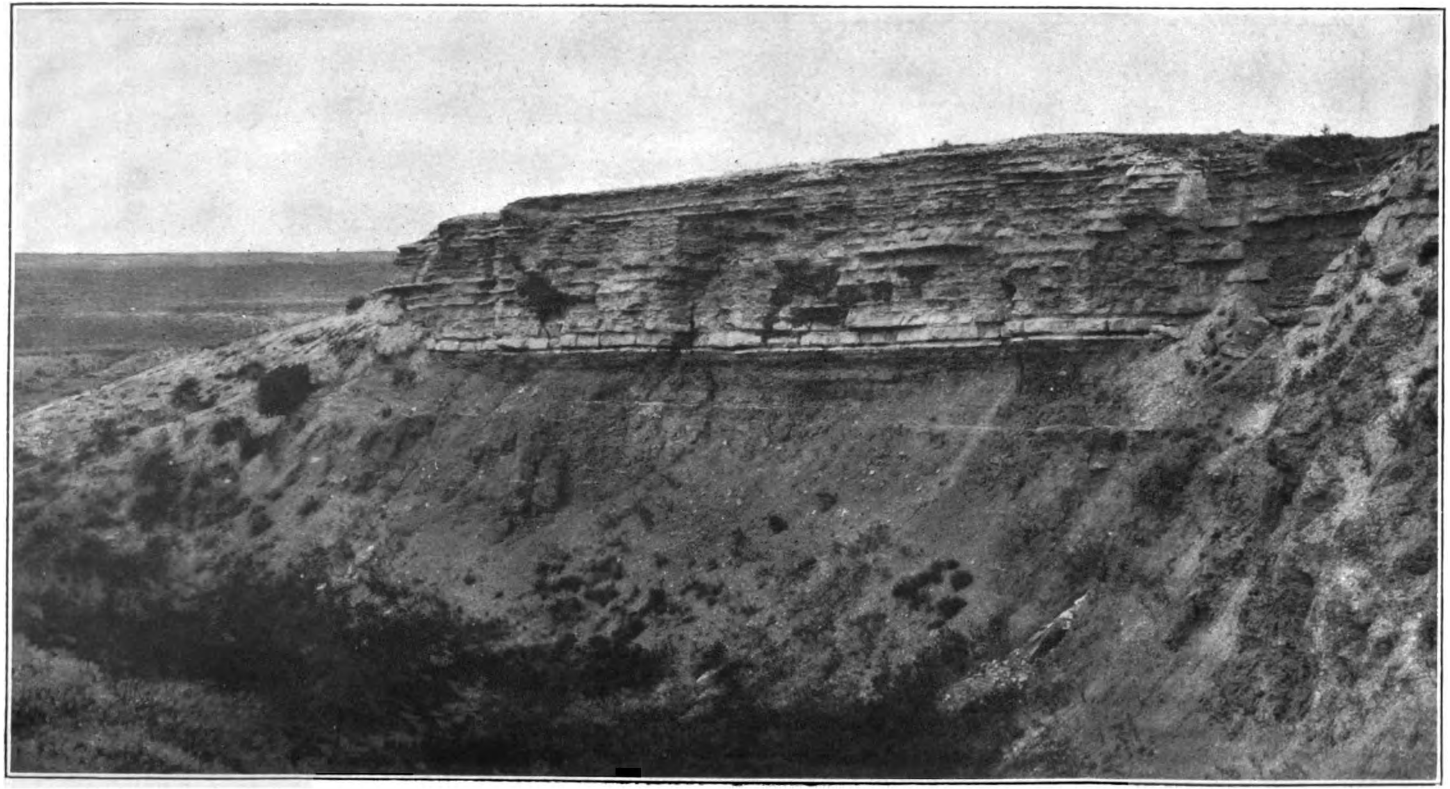
One of the most prominent features in the plains immediately adjoining the Black Hills is a low but distinct ridge or escarpment, which is due to a hard limestone bed in the middle of shales of Benton age. It usually lies 1 to 4 miles from the hogback ridge of the Dakota sandstone and faces toward the hills. It is thin but persistent and is characterized by many impressions of *Inoceramus labiatus*, a fossil of rare occurrence in the adjoining formations.

The Greenhorn limestone contains a considerable amount of clay and fine sand. It gains hardness on weathering, for in the outcrops it breaks into hard, thin, pale-buff slabs covered with impressions of the distinctive fossil. Its thickness averages about 65 feet. At its base it is usually distinctly separated from the dark Graneros shale by abrupt change in material (see Pl. IX); and in its upper portion it appears to grade into the Carlile shale through 6 or 8 feet of passage beds.

The most extensive exposures of the Greenhorn limestone are in the prominent escarpments which rise high above the slopes west and northwest of Edgemont along the south side of Cheyenne River. Owing to the low dip the limestone is spread out in plateaus which extend for some distance back from the edge of the escarpment. In the region about Fairburn the formation is traversed by a syncline, which spreads it out into a bifurcated ridge south of the town. On the adjoining divides, notably in those between French Creek and Battle Creek and between Battle Creek and Spring Creek, the formation is buried beneath the overlapping White River deposits. It is well exposed in the banks of Battle Creek 1½ miles below Hermosa, where, in its only slightly weathered condition in the fresh stream cut, it is seen to be a hard calcareous light-gray shale filled with *Inoceramus*. East of Sturgis it constitutes a ridge extending to Bear Butte. In the northern Black Hills it is conspicuous about Belle Fourche, notably in a prominent butte known as Susie Peak.



EAST SLOPE OF HOGBACK RIDGE SOUTH OF BUFFALO GAP, S. DAK., LOOKING SOUTHWEST.



GREENHORN LIMESTONE ON GRANEROS SHALE SOUTH OF EDGEMONT, S. DAK.

### CARLILE SHALE.

The Carlile shale, the uppermost formation of Benton age, consists of dark fissile shale that contains concretions, thin sandstones, and impure limestone layers lying between the Greenhorn limestone and the Niobrara formation. Near the top of the formation numerous oval concretions contain *Prionotropis*, *Prionocyclus*, and other fossils. The thickness ranges from 500 to 600 feet, except in the region north of Belle Fourche, where it is locally slightly more than 750 feet. Some typical sections follow:

*Section of Carlile shale near Buffalo Gap.*

| Niobrara formation. | Feet. |
|---|---|
| Shales, with large buff concretions | 150 |
| Hard, slabby sandstone | 2 |
| Gray shale | 130 |
| Thin coarse sandstone | 4 |
| Gray shale | 75 |
| Concretions in gray shale | 2 |
| Gray shale | 40 |
| Calcareous sandstone with *Ostrea* and other fossils | 4 |
| Shale and talus | 180 |
| Greenhorn limestone. | |

*Section of Carlile shale 1½ miles southeast of the falls of Cheyenne River.*

| Niobrara formation. | Feet. |
|---|---|
| Gray shale, with large buff concretions | 50 |
| Gray shale | 70 |
| Light-gray sandstone | 4 |
| Dark-gray shale, with thin sandy layers | 160 |
| Sandstone | 2 |
| Gray shales | 150 |
| Greenhorn limestone. | |

### NIOBRARA FORMATION.

The calcareous deposits of the Niobrara formation completely encircle the Black Hills, presenting distinctive features throughout. The material is a soft shaly limestone or impure chalk, containing greater or less admixture of clay and fine sand. In unweathered exposures it is generally light gray, but its weathered outcrops have a bright-yellow color which usually renders them conspicuous, although, owing to the softness of the materials, they form few noticeable ridges. The thickness of the formation is about 225 feet in the central and southern Black Hills and 150 to 200 feet on the northern slopes. At many places it includes thin hard layers of shells of *Ostrea congesta*, a fossil distinctive of the formation. A few hundred feet of dark overlying shales may also belong to this formation.

### PIERRE SHALE.

Many thousand square miles of the country adjoining the Black Hills are occupied by the Pierre shale, a thick mass of dark shale, weathering light brown and relatively uniform in composition throughout. It gives rise to a dreary monotony of low rounded hills, sparsely covered with grass and not very well adapted to agriculture. The thickness of the formation, so far as it can be ascertained, is 1,200 feet, but owing to the gentleness of the dip it can be measured at only a few places. Fortunately it has been found that the formation includes, about 1,000 feet above its base, scattered lenses of limestone containing numerous shells of *Lucina occidentalis.* Most of these lenses occur at a definite horizon, and in places, where they occupy the surface over a wide area, they indicate the attitude of the formation and permit estimates to be made as to the depth of the Dakota sandstone in the shale region adjoining the Black Hills.

The limestone concretions carrying *Lucina* range from 2 to 20 feet in diameter and from 6 to 8 feet in thickness and are commonly of irregular lens shape. Owing to their hardness these lenses, when uncovered by erosion, give rise to low conical buttes resembling very squat tepees (see Pl. XI), and accordingly they have been designated "tepee buttes," a term used for similar forms in the Pierre shale of southeastern Colorado. Large numbers of them rise 10 to 150 feet above the surrounding slopes in the vicinity of Oelrichs, east of Hermosa and Sturgis, and in the Willow Creek valley east and north of Newell. Horizontally the lenses occur at irregular intervals, so that the buttes are scattered very irregularly and some of them are separated by many miles.

Numerous concretions occur in the Pierre shale at various horizons and usually contain many distinctive fossils. *Baculites compressus*, *Inoceramus sagensis*, *Nautilus dekayi*, *Placenticeras placenta*, and *Heteroceras nebrascensis* are the more abundant, and *Lucina occidentalis* is found here and there. The most fossiliferous beds are in the upper part of the formation. The concretions are generally small and calcareous and break into brown pyramidal fragments which are scattered more or less thickly all over the Pierre surfaces.

In the southern part of the Black Hills region a very distinctive series of black splintery, fissile shales, containing three beds of concretions but no fossils, lies at the base of the formation. These shales have been mapped with the Pierre but may be Niobrara. They are about 150 feet thick in the Edgemont-Oelrichs region, where they give rise to a steep slope, in places rising conspicuously above the lowlands in the Niobrara chalk.

### WHITE RIVER GROUP.

Extensive areas of clay, sand, and gravel of the White River group cover some of the plateaus along the foot of the hogback ridge from a point near Rapid City to a point 15 miles southwest of Fairburn, and small remnants occur at various other points along the higher slopes of the Black Hills, notably at Lead, Maitland, and west of Argyle. The deposit forms a thick mantle on the divides between Spring and Battle creeks, Battle and French creeks, and French and Beaver creeks. Extensive masses occur in the Red Valley south of Rapid City and west and southwest of Hermosa, and some of these overlap westward through old valleys into the limestones and granites. The maximum thickness is 300 feet.

The formation consists of fuller's earth, sand, limestone, and calcareous grit; and the courses of old channels are marked by coarse gravel, in places cemented into hard conglomerate by silica or by calcium carbonate. The principal material, especially of the upper beds (Brule clay), is a porous crumbling clay, pale flesh color when dry but light brown when damp. Some portions are very pale green when dry and olive-colored when wet. Much of this fine-grained deposit is fuller's earth. These beds form badlands in many places. The lower beds (Chadron formation) are mostly coarse and, in the vicinity of Hermosa, consist of a coarse sandstone and a dark conglomerate. About Fairburn and to the west there are extensive channels filled with conglomerate of limestone pebbles in a limy matrix. On the higher lands northwest of Hermosa some beds of massive limestone are included that are in places 30 feet thick. Coarse material of White River age is extensively exposed in railroad cuts through the divide south of Fairburn, where the sands are cross-bedded. The White River deposits contain many bones of animals typical of the Oligocene.

## STRUCTURE.

### GENERAL FEATURES.

The general monocline formed by the strata dipping away from the central area of crystalline rocks of the Black Hills is interrupted by several local flexures and by many changes in the rate and direction of dip. A few faults exist, and the Bear Butte and other igneous masses break and flex the beds. An understanding of the structure of the beds is of the greatest importance in considering the underground-water problems, especially in determining the depth of the water-bearing sandstones. The principal structural features affecting the artesian conditions are shown in seven sections (see Pl. X), whose location is indicated on the map (Pl. I, in pocket).

### LIMESTONE RIDGE.

Except in the northern slope of the hills, where many minor flexures and considerable deformation have been caused by igneous intrusion, the thick sandstones and limestones of the Limestone Ridge dip away from the central area in a general monocline. On the west slope of the uplift the dips are low and the outcrop areas form a broad plateau, which, however, narrows somewhat as the dips steepen slightly west and southwest of Pringle (see sections 6 and 7) and along the east slope from Wind Cave to Rapid City, where the dips are 10° to 20°. In places the outcrop zone narrows to a steep ridge. (See sections 4, 5, and 6, Pl. X.) Northwest of Rapid City the dips diminish and the limestone plateau widens, but in the vicinity of Piedmont and Sturgis the dips along the east slope of the limestone belt are steep. A marked local arch in the beds 3 miles northwest of Rapid City is shown by the Minnekahta limestone.

### ANTICLINE AND SYNCLINE OF WHITEWOOD REGION.

Northwest of Sturgis a prominent arch rises on the limestone slope and extends to Crook, beyond which it crosses the Red Valley and causes a notable projection of the hogback ridge southeast of St. Onge. The further extension of this arch northward is well marked in the shale region about Haystack Butte, and in Susie Peak it causes a great deflection in the outcrop and ridge of Greenhorn limestone. The arch is therefore an important feature of the artesian problem, lifting the water-bearing sandstones several hundred feet in the region east of Belle Fourche.

West of this anticline is a syncline (see sections 2 and 3, Pl. X), which holds Spearfish red beds in Boulder Park and down the valley to Crook and causes the southward deflection of the Lakota and Dakota sandstones in the hogback ridge west of Whitewood. It also underlies the shale valley followed by the railroad at St. Onge and extends north a short distance east of Belle Fourche, where the water-bearing sandstones descend more than 900 feet below the surface.

### RED VALLEY IN SPEARFISH REGION.

In Centennial Prairie and the Red Valley about Spearfish, in a very broad area of northerly and northeasterly dips, the strata are nearly horizontal in places and rarely show noticeable dip. At Elkhorn Peak these beds are sharply arched by a dome bringing up a small circular mass of Minnelusa sandstone.

### BEAR BUTTE.

Bear Butte, northeast of Sturgis, is due to an igneous intrusion which has faulted up a large mass of Pahasapa and overlying strata on its east and northeast sides and which exposes the red beds of the Spearfish formation in a dome on its west slope. The disturbance of the beds is very great but relatively local, affecting an area 6 miles long from west to east and 3 miles from north to south, on all sides of which the usual monoclinal structure continues.

### HOGBACK RIDGE AND RED VALLEY SOUTH OF STURGIS.

From Sturgis for many miles southward the Red Valley and the hogback ridge present great uniformity of structure with general dip to the east. (See sections 3, 4, 5, and 6, Pl. X.) Many variations in rate occur from place to place, and northeast of Piedmont and southwest of Fairburn there are small branch anticlines in the Dakota and associated sandstones. A small anticline in limestone and red beds lies northwest of Rapid City (p. 24), and another small anticline in the Greenhorn limestone and associated shales lies just south of Fairburn.

Along the hogback ridge the dips are moderately steep, near Sturgis 12° to 15°, but they diminish to the south and in the shale area to the east. On the east slope of Piedmont Butte the Dakota sandstone dips 4°, on Elk Creek 8°, and on Rapid Creek 22°. On the west side of the anticline southeast of Piedmont a local dip of 60° is exhibited. East of Rapid City the Greenhorn limestone dips 10° E., a slope considerably steeper than in the region to the north and the south. Along the outcrop zone of the Carlile and Niobrara formations dips of 2° to 3° are numerous and some of 5° or 6° are found.

From Spring Creek southward past Hermosa the Red Valley and hogback ridge have no notable structural features, the strata dipping 5°–12° E. in a uniform monocline. On Squaw Creek the Dakota sandstone dips 9½°; 5 miles northwest of Hermosa 10°. On the divide south of Spring Creek the Red Valley is filled with White River deposits for some distance, and these also partly bury the hogback ridge. In the southeast corner of T. 3 S., R. 7 E., 8 miles southeast of Hermosa, the Dakota sandstone presents a small syncline and anticline in the midst of the White River beds.

### PASS CREEK REGION.

In the region west of Minnekahta and north of Argentine the formations dip southwest at very low angles and are exposed in broad outcrops. Near the junction of Hell Canyon and Pass Creek a low irregular dome in the Red Valley widens the outcrop of Spearfish red shale and gives rise to an outlying ridge of Minnekahta limestone. Where the dome is cut through by Tepee and Hell canyons the top of the Minnelusa sandstone is revealed. A small minor dome brings up the Minnekahta limestone in a small knoll just north of the mouth of Hell Canyon. It is due in part to the influence of this doming that the hogback ridge has a crescentic course on either side of Pass Creek Canyon. On the north side of the canyon is Elk Mountain, in which the strata dip 10° to 25° W. In the ridge east of the creek the dips are low and give rise to a wide southward-sloping plateau of Lakota and Dakota sandstones.

### PLAINS EAST OF THE BLACK HILLS.

The representation of the structure of the plains east of the Black Hills in cross sections 2 to 6 (Pl. X) and the determination of the depth to the Dakota sandstone as shown on the map (Pl. I, in pocket) are based largely on the relation and distribution of the Greenhorn limestone, Niobrara formation, and the tepee buttes in the Pierre shale. It is believed that the principal horizon of the limestone concretions causing these buttes is about 1,000 feet above the base of the Pierre shale. The region is one of low dips, the rate of inclination gradually diminishing toward the east.

In portions of the outcrop zone of the Graneros shale and the Greenhorn limestone the strata dip 5° to 10°; in the Niobrara area they rarely dip as much as 5°; in the area southeast of Hermosa they dip less than 2°. In the Pierre area the dip is difficult to determine in surface outcrops of the shale, but the general structure is indicated by the tepee buttes. It is found that the strata are nearly horizontal a few miles east of Buffalo Gap and bend into a shallow syncline on Cheyenne River about Mohler post office. On Battle Creek they slope eastward about 250 feet to the mile, gradually steepening to about 400 feet in the region east of Brennan. Northward about Bend post office the dip decreases again to 125 feet to the mile. North and northwest of Alkali post office the strata are nearly horizontal, but they rise in a long, low anticline along Belle Fourche River and probably in a faint anticline northeast of that stream.

## UNDERGROUND WATER.

### GENERAL CONDITIONS.

The slopes of the Black Hills and the plains adjoining them are underlain by 6,000 feet of sedimentary rocks, including several thick beds of water-bearing sandstone which receive their water supplies from rainfall on the higher ridges and slopes. The principal beds are the Lakota and Dakota sandstones, Minnelusa sandstone, and

Deadwood sandstone. These sandstones pass underground in consequence of the general outward dip on the sides of the uplift, and therefore in the adjoining plains they are more or less deeply buried

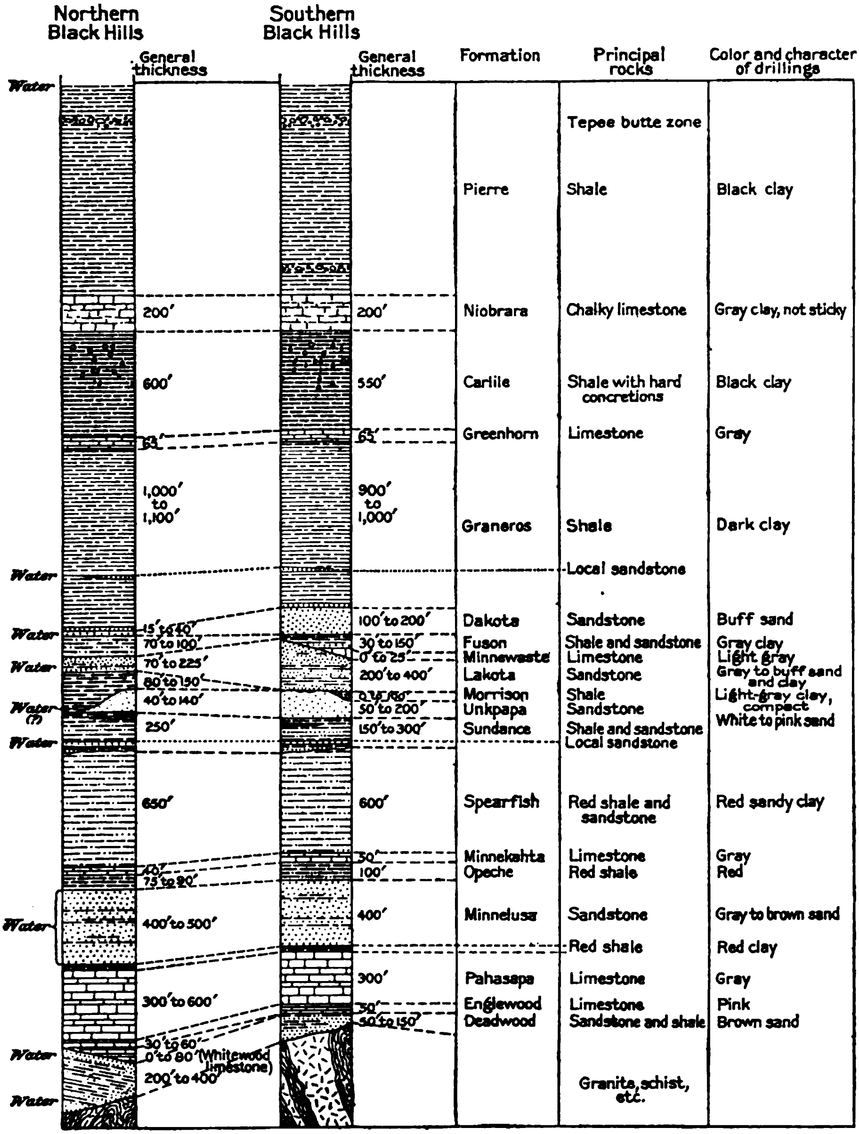


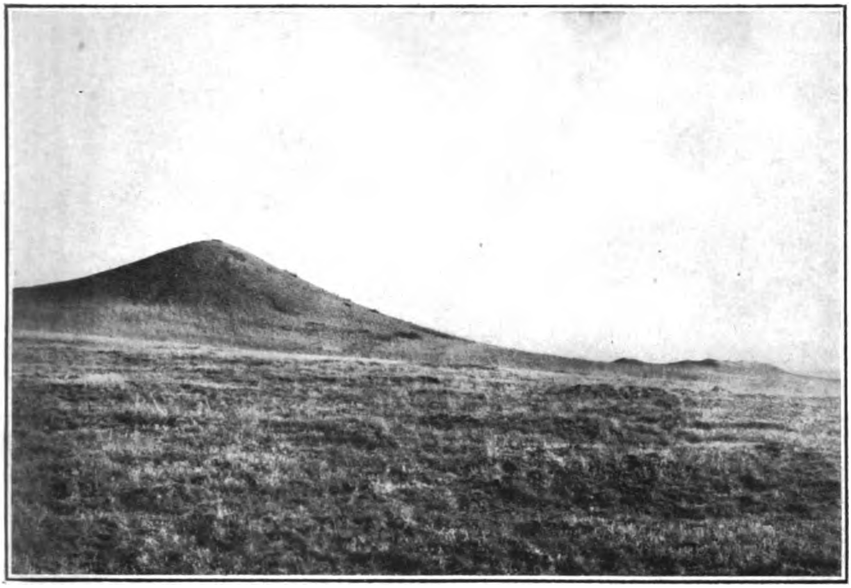
FIGURE 1.—Columnar sections of rocks in the Black Hills and vicinity, showing thickness of beds, relation of water-bearing sandstones, and color of drillings.

under a thick body of relatively impermeable shales. The steep dip along the foothills (see p. 25) carries them to a considerable depth, but in most portions of the foothills and plains one or more of them are within reach of the well borer. As this region is somewhat arid, with surface waters inadequate or of bad quality in most localities, there is great need for underground waters. Only a few wells have been sunk, but most of these have been so satisfactory that they greatly encourage drilling for large water supplies throughout the region. The relations of the water-bearing beds in the succession of sedimentary rocks in the Black Hills region are shown in figure 1. The principal water-bearing sandstones rise to the surface on the slopes of the Black Hills in regular order, as shown in the cross sections. (See Pl. X.) They crop out in wide zones encircling the uplift, and receive a large amount of water not only from the rainfall on their surface but from streams, which at many localities sink into them wholly or in part in crossing their outcrops. This sinking is observed in almost every valley leading out of the central area. Few of the streams carry into Belle Fourche or Cheyenne River more than a small portion of the original run-off of their drainage basins, for much of it sinks underground in crossing the Minnelusa, Lakota, and Dakota sandstones. The water thus absorbed by the sandstone passes far beneath the surface as the water-bearing beds descend the slopes of the uplift. Water also passes underground in caves and crevices in the limestone, some of it coming out again in springs and some of it sinking into underlying sandstone. (See Pl. XII, *A*.)

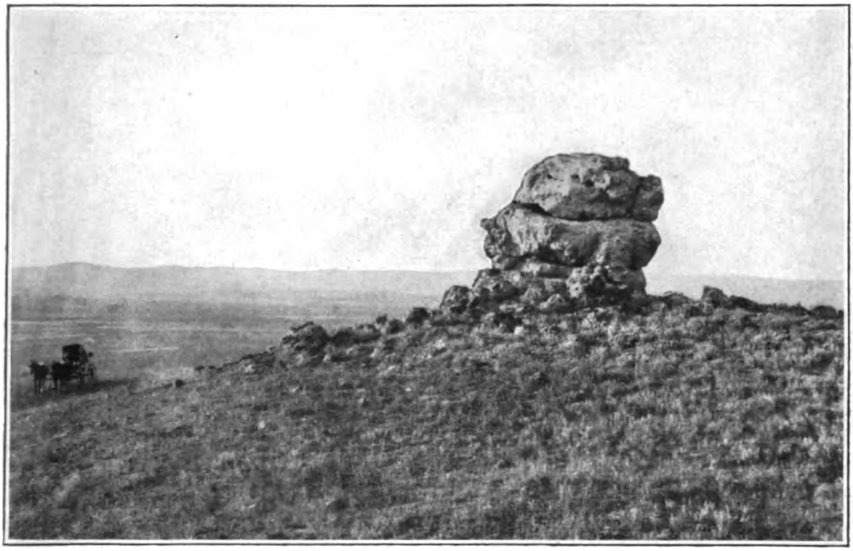
Some of the artesian water also leaks to the surface in springs, as in the warm springs at Hot Springs, at Cascade Springs (Pl. XII, *B*), and in the upper part of Buffalo Gap. This warm water comes from a considerable depth.

## DEPTHS TO ARTESIAN WATER.

The depths to the water-bearing sandstones (see map, Pl. I, in pocket, and sections, Pl. X) have been ascertained by careful measurements of the thickness of the several formations at many places throughout the Black Hills and adjoining plains. The structure and distribution of these formations have been considered in preparing the underground-water maps of the region. An important guide to the structure in part of the plains is furnished by the horizon of limestone lenses in the Pierre shale that give rise to tepee buttes. (See Pl. XI.) The thickness of the beds differs somewhat from place to place in the outcrops and doubtless varies underground, especially in the lower sandstones and limestones, which show a general thinning to the east. (See fig. 2.) These older rocks are absent under central-eastern South Dakota and the position of their eastern margins has not been ascertained.

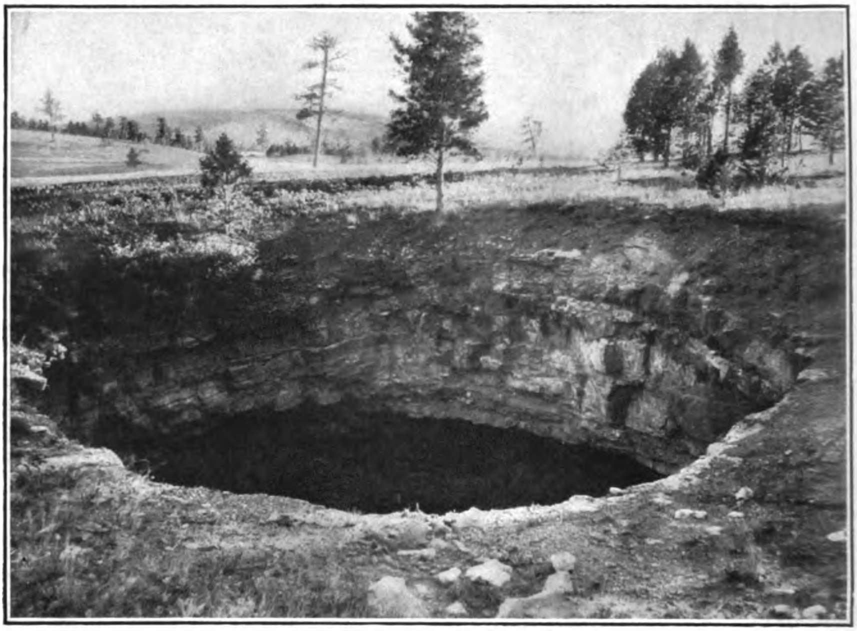


*A*. GROUP OF TEPEE BUTTES.

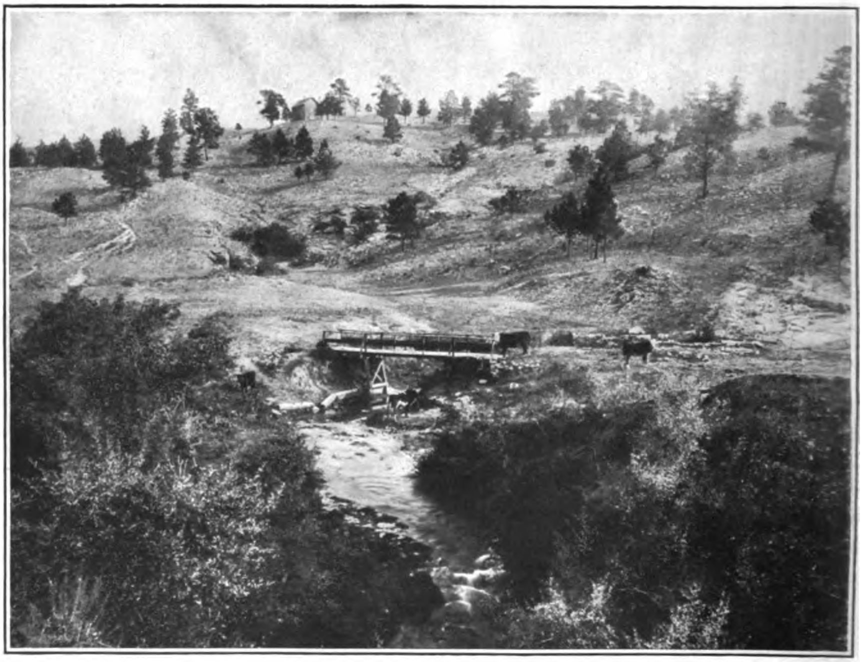


*B*. LIMESTONE CORE SUCH AS CAUSES TEPEE BUTTES.

TEPEE BUTTES DUE TO LIMESTONE LENS IN PIERRE SHALE.



*A*. SINK HOLE IN MINNEKAHTA LIMESTONE.



*B*. SPRING AT CASCADE SPRINGS, S. DAK.

## WATER-BEARING SANDSTONES.

### DAKOTA AND LAKOTA SANDSTONES.

The Dakota and Lakota sandstones are the principal beds in which artesian water is to be expected in the wide area of plains adjoining the Black Hills. The greatest volume of water is in the Lakota sandstone, but in some districts the Dakota sandstone contains a moderate supply.

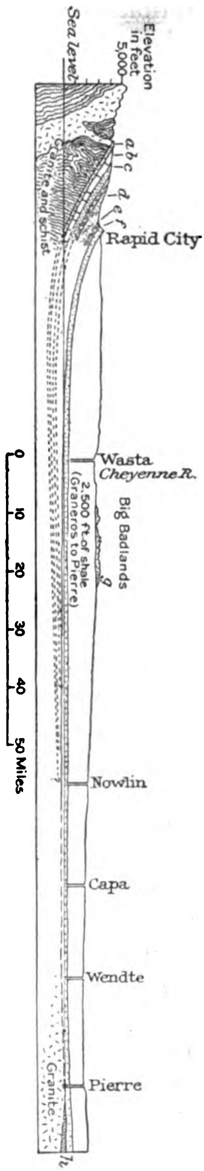


FIGURE 2.—Section across South Dakota from the Black Hills to Missouri River, showing the general relations of water-bearing rocks. *a*, Deadwood formation; *b*, Englewood and Pahasapa limestones; *c*, Minnelusa sandstone; *d*, red beds (Opeche, Minnekahta, and Spearfish formations); *e*, Sundance formation, Unkpapa sandstone, and Morrison shale; *f*, Lakota, Minnewaste, Fuson, and Dakota formations; *g*, White River group in Big Badlands; *h*, pre-Cambrian quartzite.

Both sandstones outcrop in a wide zone in the hogback ridge, where by direct absorption and by the sinking of water from streams they receive a considerable proportion of the rainfall. This water flows slowly through the permeable sandstones and finally passes far below the surface of central South Dakota and emerges in great springs and general seepage in the outcrops of Dakota sandstone in the Missouri Valley in the southeastern corner of the State.

As the water enters the Dakota and Lakota sandstones in land mostly from 3,100 to 3,500 feet above sea level and passes in them beneath a thick body of relatively impermeable shale, it should be expected to have great pressure or head in the plains to the east, which finally slope down to 1,200 feet above sea level near Missouri River. This pressure, which is found in many wells in central and eastern South Dakota, is conclusive evidence that the water flows underground for many hundreds of miles. Some wells show surface pressures of 175 to 200 pounds to the square inch, the 200 pounds indicating a pressure of 780 pounds to the square inch at the bottom of the well. Such pressures can be explained only by the hydrostatic influence of a column of water extending to a high altitude on the west. There is, however, considerable escape of water from the Dakota sandstone in its outcrops in the Sioux City region and southward, and some must seep through the overlying shale, so instead of the original head of the intake being sustained there is gradual diminution to the east and it dies out in the outcrop zone. There is therefore a grade in the head or altitude to which water can rise, a slope sustained by the friction or slowness of passage of water through the strata. A simple apparatus (see fig. 3) illustrates conditions closely similar to those in the Dakota and Lakota sandstones, which are the principal water-bearing strata under the Great Plains. The accompanying cross section (fig. 4) shows the head observed along a line from the intake zone west of Rapid City to the outlet in the Sioux City region.

From the altitude of the outcrop of the Dakota sandstone and the pressures observed in wells in central and eastern South Dakota, contour lines (see fig. 5) have been constructed to indicate the head of artesian water in the State, and it is on this basis that the "head" lines have been spaced on the map (Pl. I, in pocket). The spacing of these lines necessarily is in part theoretical, but they are required in delimiting the flowing from the nonflowing areas.

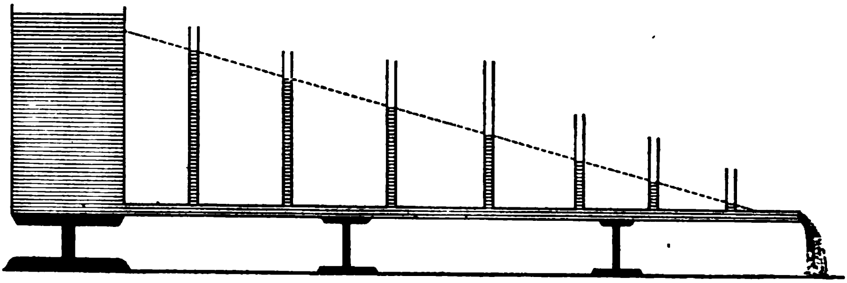


FIGURE 3.—Apparatus for illustrating the declivity of head of liquid flowing from a reservoir. The shaded portions are water.

This diminution of head (termed hydraulic grade) is shown on the map by lines indicating the height, at intervals of 100 feet, to which the underground water may be expected to rise above sea level. These lines also afford a means for estimating the pressure of the water in the area of flow, the pressure in pounds at any point being ascertained by subtracting the altitude of the land from the altitude of the head and dividing by 2.3 (the height in feet of a column of water 1 inch square, weighing 1 pound). The depth below the surface at which water would stand in a well in the area too high for a flow may be found by subtracting the altitude of head from the altitude of the land, as shown by the brown contour lines on the base map. The interval of these contour lines is 100 feet. Intermediate figures for both may be obtained by estimating proportionate distances between the lines. For instance, at Smithwick, which has an altitude of 3,225 feet and is not far above the 3,100-foot line of head, the water should be expected to rise within about 100 feet of the surface, and, as is shown by the pattern indicating depths, it would be necessary to sink a well about 2,400 feet to reach the top of the Dakota sandstone. It is possible that it might be necessary to sink 150 to 200 feet deeper through the Fuson shale and Minnewaste limestone into the Lakota sandstone before a large volume of water could be obtained.

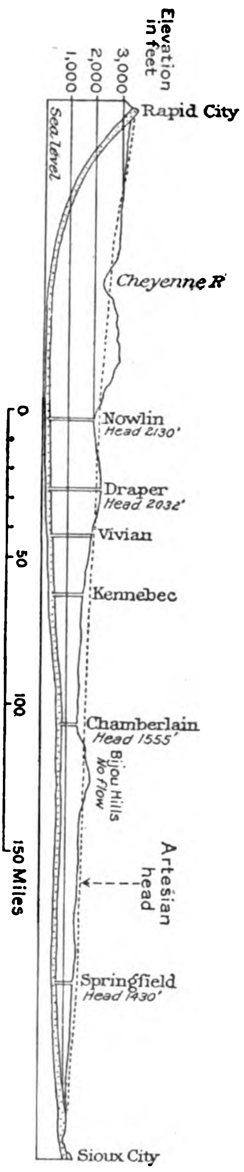


FIGURE 4.—Profile from the Black Hills to Sioux City, Iowa, showing the gradient in the head of artesian water of the Dakota and Lakota sandstones from intake to outflow. Broken line is hydraulic gradient. Dotted band is Dakota sandstone. Vertical scale is greatly exaggerated.

The areas in which the head of water is sufficient to afford surface flow and areas in which a flow is not available are shown in different colors. The areas of flow as deduced from the calculated head of the water comprise the valleys of Cheyenne River, Beaver, Lame Johnny, French, Dry, Battle, Spring, Rapid, Box Elder, Elk, Alkali, Bear Butte, Volunteer, Whitewood, False Bottom, Hay, Elm, and Willow creeks, and Belle Fourche River, but, owing to lack of precise data in most of the region, the limits are only approximate. It will be noticed that the altitudes to which the water may be expected to rise decrease regularly toward the east, for it is in that direction (away from the source of supply) that the altitude of head gradually diminishes.

The water from the Dakota and Lakota sandstones is the source of supply for numerous wells 400 to 2,000 feet deep, which furnish large volumes of water in eastern and central South Dakota and about Belle Fourche, and it is believed that this water is also available under the extensive plains lying immediately east of the Black Hills. On the map (Pl. I, in pocket) the depths to the top of the Dakota sandstone are shown by patterns in color, each of which includes between its limits a difference of 500 feet; thus, one represents depths less than 500 feet, the next from 500 to 1,000 feet, and so on.

On the columnar section (fig. 1, p. 27) are shown the beds which have to be penetrated in drilling. These can be recognized by their characteristics and relations as shown in this section and described in the table (p. 9). Two fossils, *Ostrea congesta* and *Inoceramus labiatus* (Pl. XIII), are important guides in determining the identity of two prominent formations which underlie the plains area. The *Ostrea congesta* occurs crowded together and constituting thin shelly layers in the upper portion of the Niobrara chalky shale, which although bright yellow when exposed on the surface, is pale blue-gray when first brought out by the well boring. The *Inoceramus* is characteristic of the Greenhorn limestone, which is hard and buff-colored on the surface, as seen in the many outcrops in the escarpment just east of the hogback ridge, but is dark gray and soft textured underground. The zone of concretions and the thin layers of sandstone in the Carlile shale will be encountered by the well borer and recognized by their hardness and their relations to adjoining beds. (See fig. 1, p. 27.)

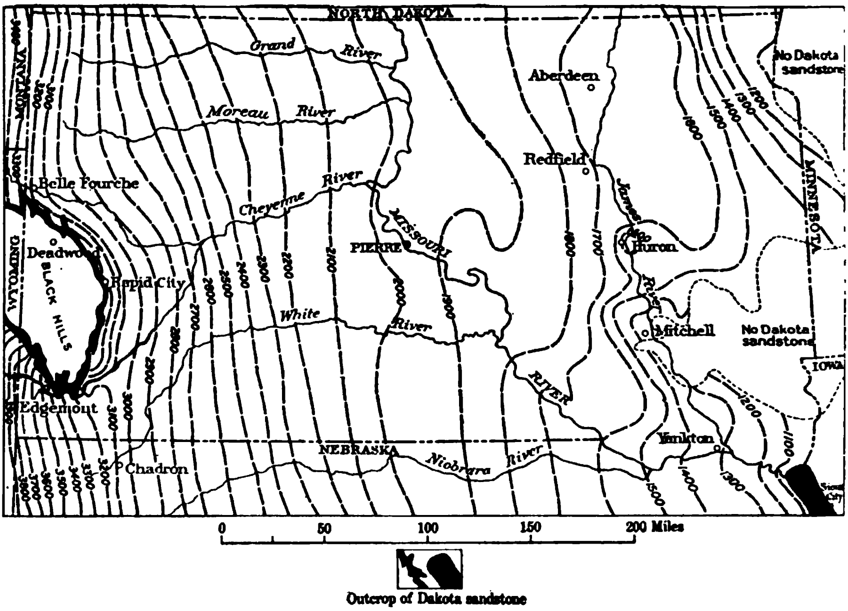
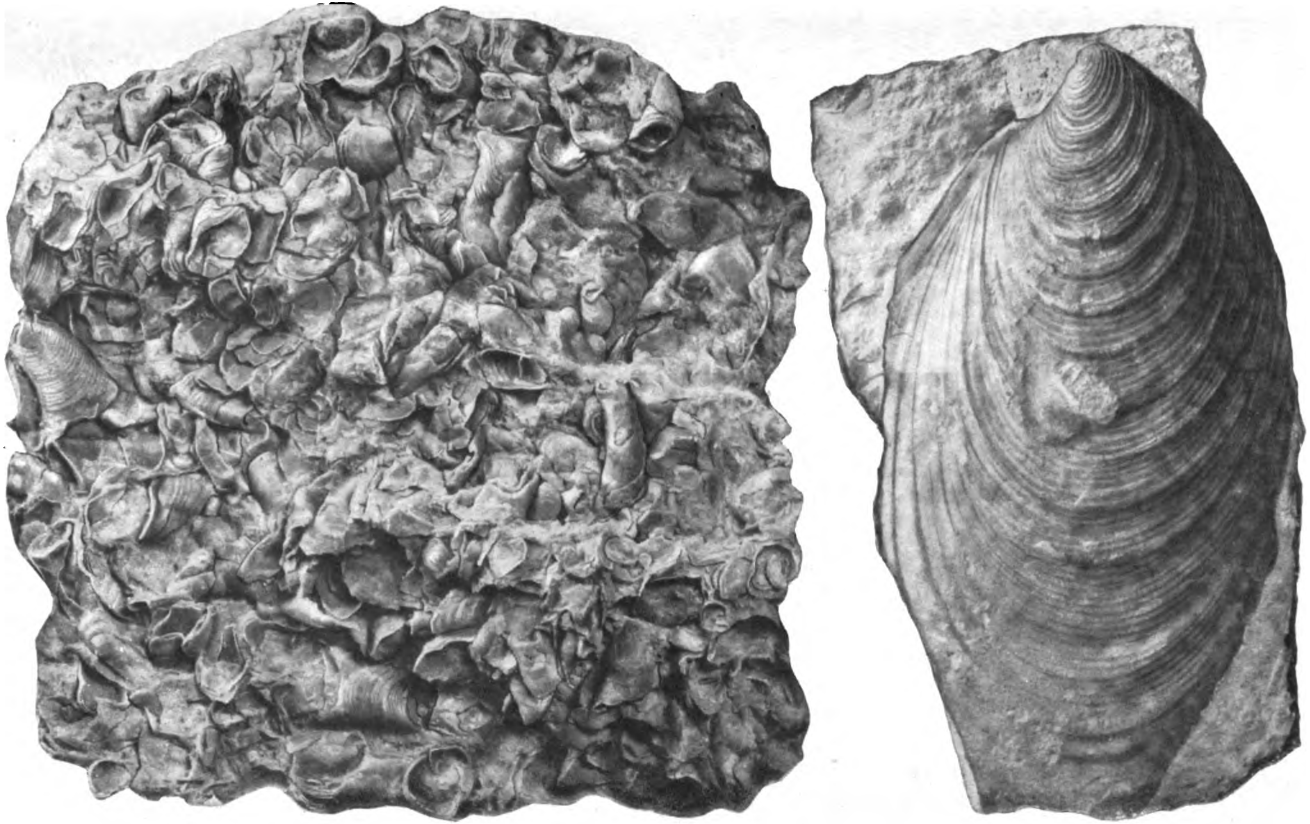


FIGURE 5.—Outline map of South Dakota showing hydraulic gradient by contour lines of head.

### FORMATIONS BETWEEN THE LAKOTA AND MINNELUSA SANDSTONES.

In the Morrison and Sundance shales underlying the Lakota sandstone there are no prospects for water, but in the sandstone members in the lower portion of the Sundance formation there is a small



*A.* *B.*

CHARACTERISTIC FOSSILS THAT SERVE AS GUIDES IN WELL BORING IN THE PLAINS.

*A*, Ostrea congesta of Niobrara formation; *B*, Inoceramus labiatus of Greenhorn limestone.

amount, as illustrated by the well at the Bowman ranch, 6 miles north of Sturgis. At this place the water had somewhat greater head than that in the Lakota sandstone and therefore gave a flow, though one of small volume. At Fort Meade and Chambers ranch it did not flow. Possibly at some places these sandstones will yield more satisfactory results.

The Unkpapa sandstone, between the Sundance shale and Morrison formation in the eastern and southeastern part of the Black Hills, may prove to be water bearing, but apparently it is too fine grained or compact to carry a great volume of water. The great mass of gypsiferous red shale of the Spearfish and Opeche formations is not likely to yield much water, and if a small volume is obtained it will probably be highly mineralized. The absence of water in these formations was demonstrated at the deep borings at Edgemont, Spearfish, near Belle Fourche, and Minnekahta, and also at Fort Meade, a short distance east of Sturgis, where the Opeche red beds were reached and no supply was found below a small flow from the Dakota sandstone. It is possible that the shallower wells near Spearfish draw from sandstones in the red beds, for they are not deep enough to reach the Minnelusa sandstone, but it is more likely that they tap upward seepage from the Minnelusa. The Minnekahta limestone is too dense to carry water, notwithstanding its cavernous character in some places near the surface.

### MINNELUSA SANDSTONE.

As shown in the sections the outer slopes of the Black Hills and the adjoining plains (see Pl. X, p. 26, and fig. 2, p. 29) are underlain by the Minnelusa sandstone, which lies at great depth along the eastern side of the area but rises to the surface in the region of the limestone foothills. In its outcrops this formation appears to consist mostly of very porous sandstone, likely to imbibe much surface water and to constitute a water-bearing stratum available for deep wells. The numerous springs which emerge in places from the upper sandstone furnish a further indication of its properties in this regard. In wells at Cambria on the west side and at Edgemont and Minnekahta on the south side of the Black Hills the sandstone is very fine textured and the sand grains are so closely cemented by lime that the interstices are filled up, leaving little room for water. In the northern part of the Black Hills region, however, the sandstone is much coarser grained and appears to be less calcareous, especially the upper member of massive white to buff sandstone (see Pl. II, *B*, p. 10), which supplies flowing wells near Rapid City and Spearfish and would probably yield flowing water in most other portions of the region on the north and east sides of the Black Hills. As shown on the map (Pl. I, in pocket) this upper sandstone lies at moderate depth in the Red Valley, but to the east its depth gradually increases to several thousand feet near Cheyenne and Belle Fourche rivers.

In the boring at Fort Meade the red beds of the Spearfish formation are about 695 feet thick, and as the Minnekahta limestone and Opeche red beds are only about 130 feet thick the maximum depth to the top of the Minnelusa sandstone is only about 800 to 1,000 feet along the outer margin of the Red Valley and much less as the slopes of Minnekahta limestone are approached. Possibly in places it would be necessary to sink 300 to 400 feet through the Minnelusa beds to reach the water in the lower sandstone, but the prospects are fairly good that a sufficient supply will be found in the upper sandstone, as at Rapid City and Spearfish. As the formation outcrops high on the slopes of the ridges west and southwest of the Red Valley the Minnelusa water may be expected to show considerable head when tapped by wells on the lower lands.

### PAHASAPA AND UNDERLYING LIMESTONES.

The Pahasapa limestone, which underlies the Minnelusa sandstone, appears to be too dense to yield water except possibly along some higher slopes where caverns may be penetrated. The same conditions prevail in the thin Englewood and Whitewood limestones which underlie the slopes of the northern hills.

### DEADWOOD FORMATION.

The upper and lower sandstones of the Deadwood formation contain water and are the sources of springs along their outcrop or its vicinity. Doubtless these sandstones also contain water throughout their underground extension and could be reached by wells of moderate depth in portions of the area, but unfortunately, as shown in the cross sections (Pl. X, p. 26, and fig. 2, p. 29), they are very deep on the outer slopes of the Black Hills and in the adjoining valleys. The two deep borings at Edgemont and the one at Cambria are believed to draw from this source, and in other parts of the region where the Dakota, Lakota, and Minnelusa waters are unsatisfactory it will be desirable to sink to the Deadwood sandstone. The depth to this sandstone is indicated on the map (Pl. I, in pocket) and also in the sections (Pl. X and fig. 2). Its relations to overlying rocks are shown in the sections and also in figure 1 (p. 27). It will be seen that in the Red Valley the depth ranges from 900 to 2,000 feet: along the Dakota-Graneros contact, or outer edge of the hogback ridge, it is about 2,300 feet; at Edgemont it is 2,516 feet; and it gradually increases as the distance from the Black Hills increases, probably to 4,200 feet near longitude 103° W. How far east the sandstone extends is not known. (See fig. 2, p. 29.) The area in which flows may be expected from the Deadwood sandstone is probably great, for the altitude of intake is mostly above 5,000 feet, or higher than all of the lands east of the limestone ridges. The pressure at Edgemont of 75 pounds to the square inch is sufficient to raise the water 240 feet above the mouth of the well, or to an altitude of 3,690 feet. This is high enough to afford a flow in most portions of the Red Valley, especially as the rate probably increases somewhat toward the elevated outcrop or intake zone.

## BORINGS AND ARTESIAN PROSPECTS.

### BELLE FOURCHE REGION.

*General features.*—There are many artesian wells in the Belle Fourche and tributary valleys at and near Belle Fourche. They draw from the Dakota and Lakota sandstones and range in depth from 240 to 2,019 feet, the depths increasing gradually with distance from the foot of the Black Hills. Generally there are two or more flows, the uppermost from the Dakota sandstone, small in volume but relatively soft, and the second and lower flows, much greater in volume and harder in quality, from the Lakota sandstone 100 feet or more below. The head is sufficient to afford flows in a wide area of the lower lands, but a few borings on higher slopes have failed to obtain flows.

*Artesian wells and deep borings in the Belle Fourche region.*

| | Depth. | Depth to main water-bearing bed. | Diameter. | Reported natural flow. | Pressure. |
|---|---|---|---|---|---|
| Belle Fourche city wells: | *Feet.* | *Feet.* | *Inches.* | *Gallons per min.* | *Pounds per sq. in.* |
| No. 1 | 550 | .......... | .......... | .......... | 55 |
| No. 2 | 525 | 525 | .......... | 2 00 | 45 |
| No. 3 | 881 | 560 | 4 | 30 | .......... |
| Belle Fourche, many small wells | .......... | (a) | 1–2 | 1 | .......... |
| Belle Fourche, Craft's addition | 897 | [b] 560 | .......... | 45 | 55 |
| Land & Cattle Co., NW. ¼ sec. 11, T. 8 N., R. 2 E. | 635 | [c] 635 | 1 | Many. | 55 |
| Do | 745 | [d] 680 | .......... | 15 | 40 |
| F. A. Durst, NW. ¼ sec. 14, T. 8 N., R. 2 E. | 550 | 500 | 4½ | 100 | 26+ |
| F. N. & G. S. Fuller, NW. ¼ sec. 6, T. 8 N., R. 3 E. | 835 | [a] 800 | 2 | 30 | 15 |
| J. A. Gilbert, SE. ¼ sec. 36, T. 9 N., R. 2 E. | 836 | [e] 836 | 2 | 15 | Flows. |
| Orman & Crook, NE. ¼ SW. ¼ sec. 19, T. 9 N., R. 4 E. | 1,417 | [f] 1,325 | 3–2 | 50 | .......... |
| H. L. Barnett, SE. ¼ sec. 31, T. 9 N., R. 3 E. | 935 | (a) | 2 | 5 | .......... |
| J. Wichert, SE. ¼ sec. 24, T. 8 N., R. 2 E. | 381 | [a] 360+ | .......... | 2 | 30 |
| Case ranch, SE. ¼ sec. 14, T. 8 N., R. 2 E. | 241 | (a) | 1½ | 2 | .......... |
| Do | 355 | (g) | 4½ | 40 | 26 |
| G. H. Ray, SE. ¼ sec. 12, T. 8 N., R. 2 E. | 818 | [h] 760 | 2 | 5 | .......... |

[a] First flow; soft water.
[b] Second flow; small flow at 340 feet.
[c] Second flow; hard water; first flow at 450 feet. In valley.
[d] Second flow; water also at 450 and 650 feet.
[e] Soft water; some water at 600 feet.
[f] Flow also at 1,345 feet.
[g] Soft water.
[h] Hard water; water also at 500 feet.

*Artesian wells and deep borings in the Belle Fourche region*—Continued.

| | Depth. | Depth to main water-bearing bed. | Diameter. | Reported natural flow. | Pressure. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gallons per min.* | *Pounds per sq. in* |
| U. S. Reclamation Service, sec. 36, T. 9 N., R. 2 E. | 627 | [a] 625 | 2 | 20 | ........ |
| U. S. Reclamation Service, SE. ¼ sec. 18, T. 9 N., R. 4 E. | 1,388 | 1,380 | 2 | 1 | 9+ |
| Newland ranch, SW. ¼ sec. 4, T. 8 N., R. 3 E. | 1,033 | 1,013 | 2 | 15 | 15 |
| Brants Road ranch, SE. ¼ sec. 23. T. 10 N., R 2 E. | 2,019 | ........ | ........ | ........ | Flows. |
| Fred Ross, NW. ¼ sec. 4, T. 9 N., R. 4 E. | 1,858 | (b) | 1½ | 3½ | ........ |
| M. Snyder, SE. ¼ sec. 13, T. 8 N., R. 4 E. | 1,096½ | [b] 1,080 | 2 | 60 | Flows. |
| J. A. Scotney, NE. ¼ sec. 20, T. 8 N., R. 2 E. | 330 | ........ | 4 | 25 | 30 |
| Do | 225 | (c) | 6 | 15 | ........ |
| S. Johnson, SW. ¼ sec. 13, T. 8 N., R. 2 E. | 330 | ........ | ........ | ........ | 15 |
| W. R. Glassie, NE. ¼ sec. 28, T. 8 N., R. 2 E. | 820 | (d) | ........ | ........ | 5 |
| D. Richardson, Hay Creek, 6 miles west of Belle Fourche | 220 | ........ | 4 | 25 | ........ |
| T. Rawlins, SW. ¼ NE. ¼ sec. 17, T. 8 N., R. 2 E., 2½ miles southwest of Belle Fourche | 535 | [e] 515 | 3 | 5 | 10+ |
| H. M. Stearns, SE. ¼ NW. ¼ sec. 13, T. 8 N., R. 3 E. | 600 | ........ | ........ | 450 | 125 |
| Schaffer ranch, SW. ¼ sec. 14, T. 9 N., R. 2 E. | [f] 900 | ........ | ........ | ........ | ........ |
| R. D. Evans, sec. 6, T. 8 N., R. 2 E. | 960 | [g] 470 | 3 | 15 | 20 |
| William Barbour, NE. ¼ sec. 35, T. 9 N., R. 1 E. | 350± | ........ | 4 | ........ | ........ |
| J. Chambers, SE. ¼ sec. 17, T. 8 N., R. 1 E. | 280 | [h] 180 | ........ | ........ | ........ |
| J. Chambers, NE. ¼ sec. 20, T. 8 N., R. 1 E. | [i] 356 | [h] 310 | ........ | ........ | ........ |
| J. Chambers, NW. ¼ sec. 8, T. 8 N., R. 1 E. | 700 | ........ | ........ | ........ | ........ |

[a] First flow at 567 feet.
[b] First flow; soft water.
[c] Hard water.
[d] Second flow.
[e] First flow at 330 feet.
[f] In progress, in shale.
[g] Soft water; water also at 274 feet.
[h] Hard water within 9 feet of surface; abandoned.
[i] Water within 100 feet of surface; into red beds 120 feet; abandoned.

*Belle Fourche and vicinity.*—Since 1904 Belle Fourche has been supplied by water from artesian wells which penetrate the Dakota or underlying Lakota sandstone. The water in the deeper wells has sufficient pressure to flow into a tank 75 feet above the ground on a knoll just south of the railroad depot. Shallower wells afford supplies at a number of residences. The first well had a depth of 525½ feet and flowed 60 gallons a minute, and originally the pressure was considerably more than 55 pounds to the square inch. The well finally got out of order, apparently owing to a break in the casing, and other wells were sunk, which obtained additional supplies. The materials penetrated in the first well were as follows:

*Record of first well at Belle Fourche.*

| | Feet. |
|---|---|
| Shale | 0–207 |
| Sandstone (Dakota), yielding a small flow at 245 feet | 207–307 |
| Soft clay (Fuson), containing a thin layer of sand yielding a small second flow | 307–425 |
| Sandstone (Lakota) | 425–525½ |

The Lakota sandstone contained water at several horizons, the volume and head gradually increasing with depth, and the maximum flow being at a depth of about 510 feet, in the lower part of the formation.

The second well, on somewhat lower land near the center of the village, had the following record:

*Record of second well at Belle Fourche.*

| | Feet. |
|---|---|
| Shale | 0–300 |
| Hard sandstone (Dakota), small flow | 300–330 |
| Soft sandstone (Dakota), flow at 410 feet | 330–410 |
| Red, white, and mottled clay (Fuson) | 410–435 |
| Gray sandy clay and sandstone with lignite fragments (Lakota) | 435–470 |
| Sandstone (Lakota) | 470–525 |

A pressure of 45 pounds was reported in this well.

A third well, bored in 1903 to a depth of 881 feet, found water-bearing strata at intervals from 297 to 560 feet. This well is 4 inches in diameter and has a flow of 30 gallons a minute. Several small wells in the village are supplied by the first flow at depths of 300 to 400 feet.

A well in Craft's addition, three-fourths of a mile east-southeast of well No. 1, obtains water with a pressure of 55 pounds from the second flow at a depth of 560 feet. This well was drilled to 897 feet, with no increase of flow below 560 feet.

There are two artesian wells on property of the Belle Fourche Land & Cattle Co. in the NW. ¼ sec. 11, T. 8 N., R. 2 E., a mile north of Belle Fourche. The first, which was sunk in 1904, has a depth of 650 feet. It draws from the second flow at 635 feet. The water is somewhat hard and the pressure is 55 pounds. A flow of softer water was found at a depth of 450 feet, which is the first flow. The following record is given:

*Record of artesian well 1 mile north of Belle Fourche.*

| | Feet. |
|---|---|
| Shale | 0–350 |
| Sandstone (Dakota) | 350–450 |
| Shale and clay (Fuson) | 450–550 |
| Sandstone (Lakota) | 550–650 |

A second well on a small knoll north of the river in the northwest quarter of the same quarter section has a depth of 744 feet. It yields a 15-gallon flow of soft water under a pressure of 40 pounds. A small flow was found at a depth of 650 feet in this well.

F. Durst has a well in the NE. ¼ NW. ¼ sec. 14, T. 8 N., R. 2 E., on a hill about 70 feet above Belle Fourche. It was sunk in 1906 and has a diameter of 4½ inches and a depth of 550 feet. The main flow was reached at 500 feet and minor flows at 350 and 400 feet. The pressure is sufficient to raise the water 60 feet above the surface, with a volume of 100 gallons a minute. The water is fairly soft. The following record is supplied by the driller:

*Record of Durst artesian well, south of Belle Fourche.*

| | Feet. |
|---|---|
| Sand and gravel | 0- 20 |
| Black shale | 20-220 |
| Gray shale | 220-320 |
| Sandstone | 320-332 |
| Shale | 332-422 |
| Clay and shale | 422-442 |
| Hard close sandstone; no water | 442-492 |
| Soft white sandstone; much water | 492-550 |

Two wells on the Case ranch, a mile farther south, have depths of 241 and 355 feet and yield good flows of soft water. The deeper well shows a pressure of 26 pounds.

Another shallow well just south of Minnesela, 381 feet deep, has a 2-gallon flow of soft water under a pressure of 30 pounds.

The Gilbert, Barrett, and Fuller wells, on the south side of Belle Fourche River 2 to 3 miles below Belle Fourche, range from 835 to 935 feet in depth. They have large flows of soft water from the Dakota sandstone or "first flow." The well on the Newland ranch in the SW. ¼ sec. 4, T. 8 N., R. 3 E., with a depth of 1,033 feet, reaches this flow at 1,013 feet. This well is in the deeper part of the syncline that crosses Belle Fourche River 5 miles below Belle Fourche and had to penetrate nearly the entire thickness of Graneros shale.

*Belle Fourche project.*—The United States Reclamation Service drilled two artesian wells in connection with the Belle Fourche project—one at the dam site on Owl Creek, in the SE. ¼ SE. ¼ sec. 18, T. 9 N., R. 4 E., the other at the intake of the diversion canal 1¼ miles below Belle Fourche.

The well at the dam site is 1,386 feet deep and 2 inches in bore and has a 1-gallon flow under pressure sufficient to raise the water 20 feet or more above the surface. The boring was in Carlile and Graneros shales, with hard streaks at 250, 540, 640, 790, 900, and 1,300 feet, the one at 250 feet probably representing a portion of the Greenhorn limestone. The Dakota sandstone was entered near the bottom, so the well is supplied by the first flow. A partial analysis of the water from this well shows that it contains about 700 parts per million of total solids, about 60 parts per million of sodium, a smaller amount of calcium and magnesium, and no sulphate.

The well at the intake of the diversion canal is on the north bank of Belle Fourche River, in the SW. ¼ sec. 36, T. 9 N., R. 2 E. It is 627 feet deep and 2 inches in diameter, and obtains its supply from a depth of 625 feet. A first flow was found in the Dakota sandstone at a depth of 567 feet; shale (Fuson) separates the two flows. The following analysis of the water was made by F. M. Eaton:

*Analysis of water of Reclamation Service artesian well at intake 1½ miles below Belle Fourche.*

| | Parts per million. |
|---|---|
| Calcium (Ca) | 9.7 |
| Magnesium (Mg) | 2.4 |
| Sodium and potassium (Na+K) | 154 |
| Carbonate radicle ($CO_3$) | 16 |
| Bicarbonate radicle ($HCO_3$) | 222 |
| Sulphate radicle ($SO_4$) | 141 |
| Chloride radicle (Cl) | 16 |
| Nitrate radicle ($NO_3$) | .04 |
| Total dissolved solids | 482 |

*Hay Creek valley.*—There are deep wells at intervals up Hay Creek valley, most of which yield flows. At the Scotney ranch, in the northeast corner of sec. 20, T. 8 N., R. 2 E., there are two artesian wells, one 225 feet deep which flows 15 gallons, and another on slightly higher ground 330 feet deep which has a 28-gallon flow under a pressure of 30 pounds. The water is hard. At the Rawlins ranch, in the NE. ¼ sec. 16 of the same township, a boring 535 feet deep yields a 5-gallon flow and had a small first flow at 330 feet. The pressure is 10 pounds or more. At the Richardson place at the crossing 6 miles above Belle Fourche a well 220 feet deep has a 25-gallon flow. It begins in the Fuson formation and reaches water in the basal portion of the Lakota sandstone.

*Chambers ranch.*—On the Chambers ranch, in the SW. ¼ NW. ¼ sec. 8, T. 8 N., R. 1 E., on the hogback ridge 9 miles west of Belle Fourche, a boring was made in 1899 to a depth of 700 feet. It obtained no flow and was finally abandoned. The record is shown in figure 6 (p. 40).

The boring began at the top of the Dakota sandstone and penetrated that formation and the underlying Fuson and Lakota formations within the first 200 feet. The water at a depth of 180 feet was in the Lakota sandstone, which affords the large flows in the valleys about Belle Fourche, but the boring was on land more than 100 feet too high for a flow. The reddish sandstone at 490 to 540 feet was in the Sundance formation, and the water at 540 feet was in the sandstone near the lower portion of that formation. The Spearfish red beds were entered at a depth of 580 feet and penetrated 120 feet. It is unfortunate that this hole was not deep enough to reach the Minnelusa sandstone.

Two borings 280 and 356 feet deep were sunk on the north side of Hay Creek in the southeast corner of sec. 17 and the NE. ¼ sec. 20, T. 8 N., R. 1 E. They penetrated Sundance beds and found some water rising within 9 feet of the surface. Both wells were abandoned.

*Orman.*—The Orman well is in the NE. ¼ SW. ¼ sec. 19, T. 9 N., R. 4 E., at the south end of the Owl Creek dam. It was finished in October, 1906. The diameter of the well is 3 inches and its depth is 1,417 feet. The water-bearing bed was entered at a depth of 1,325 feet and is a very coarse sandstone 40 feet thick. The flow at an altitude of 3,017 feet, or 18 feet above the ground, is 50 gallons a minute; 26 feet higher it is 32 gallons. The temperature of the water is 94°. Another well 6 inches in diameter was drilled on ground 45 feet higher a few rods farther south. An analysis of the water from the 3-inch well by W. A. Converse is as follows:

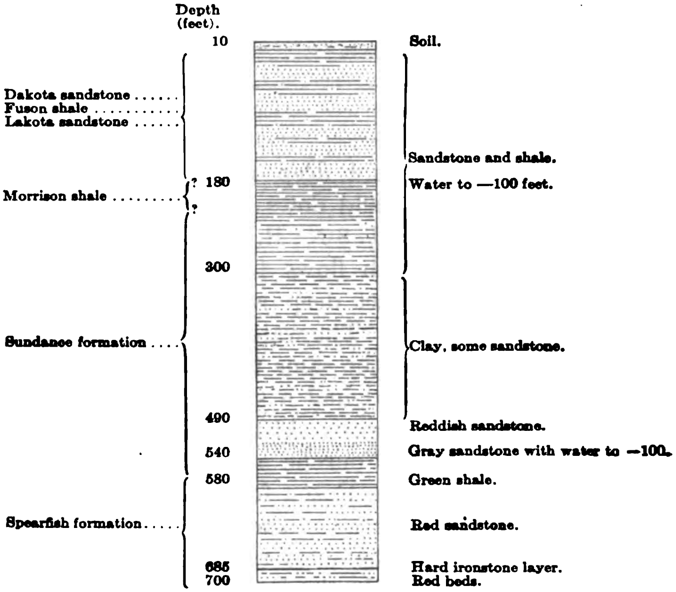


FIGURE 6.—Section of boring at Chambers ranch, 9 miles west of Belle Fourche, S. Dak.

*Analysis of water from 3-inch well at Orman.*

| | Parts per million. |
|---|---|
| Silica ($SiO_2$) | 13 |
| Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$) | 2.7 |
| Calcium (Ca) | 183 |
| Magnesium (Mg) | 57 |
| Sodium and potassium (Na+K) | 86 |
| Bicarbonate radicle ($HCO_3$) | 248 |
| Sulphate radicle ($SO_4$) | 640 |
| Chloride radicle (Cl) | 3.5 |
| Nitrate radicle ($NO_3$) | .00 |
| Organic and volatile matter | .5 |
| Total solids (by summation) | 1,107 |

*Snoma.*—A well on the Stearns ranch, a mile northwest of Snoma, near Fruitdale post office, is 600 feet deep and yields a flow reported to be 450 gallons a minute under a pressure of 125 pounds.

*Area of flow.*—The map (Pl. I, in pocket) shows the area in which flowing wells may be expected. The representation is based on the pressures reported in a number of wells and on the theoretical head which should be expected from the altitude of the outcrops of the water-bearing sandstone in the hogback ridge. Owing to the small amount of evidence available the boundaries of the area are only approximately known, and it should be borne in mind that they differ somewhat for the different flows. Ordinarily the water from the basal beds of Lakota sandstone has the greatest pressure, so that it will flow at higher altitudes than the water from the Dakota sandstone, or "first flow." The pressures in the wells in Belle Fourche indicate that the head of the water is sufficient to raise it to an altitude of about 3,150 feet, and the pressure in wells on higher lands to the south indicate a somewhat higher head, although these wells have less surface pressure. The head indicated by the reported pressure in the Stearns well near Snoma is 3,220 feet. The head diminishes toward the east, and in the valley of Indian Creek it is less than 3,000 feet. The well at the Ross ranch, however, indicates that the head would afford a flow at altitudes of somewhat more than 2,885 feet. The flow at Brant's road ranch, in the Owl Creek valley north of Belle Fourche, indicates that in that vicinity the water would rise to an altitude of more than 3,060 feet. Unfortunately the pressure of this well was not ascertained, so that the maximum altitude of head can not be calculated. The flowing well 2 miles south of St. Onge adds confirmatory evidence to the belief that flows may be obtained up to the base of the hogback ridge. Doubtless also the flow area will be found to extend up some of the valleys part way across the hogback ridge, to the line along which the base of the Lakota sandstone passes underground.

It is probable that artesian flows may be obtained from the upper part of the Minnelusa sandstone in the Red Valley area and adjoining slopes. (See p. 24.)

### ST. ONGE AND WHITEWOOD REGION.

At St. Onge a 617-foot well yields a good supply of water from the Lakota sandstone. The diameter of this well is 2 inches, the flow 125 gallons a minute, and the pressure is stated to be 20 pounds to the square inch. Another well of the same size, three-fourths mile east of St. Onge, is 653 feet deep and has a 150-gallon flow. The same artesian conditions extend up the shale valley southeastward for 6 to 8 miles and the beds gradually come nearer the surface. A 175-foot well on False Bottom Creek, 2 miles due south of St. Onge, yields an excellent flow from the Lakota sandstone. Whitewood is in the Red Valley near the line of contact of the red shales and the overlying Sundance formation. It is probable that the Minnelusa sandstone would yield a flow at this place, for the conditions are closely similar to those at Spearfish and Rapid City, where good flows are obtained. The depth to the top of the Minnelusa sandstone is greater, however, because 550 to 600 feet of red shale of Spearfish formation have to be penetrated, 35 feet of Minnekahta limestone, and 90 feet of Opeche red beds; probably 700 feet in all. Possibly it would be necessary to sink some distance into the Minnelusa sandstone to obtain a flow. About 1,100 feet deeper is the upper sandstone of the Deadwood and 1,400 feet deeper the basal Deadwood sandstone, both of which offer good prospects for artesian flows.

The same conditions exist in the Red Valley southeastward to Sturgis and also up the narrow valley past Crook into Boulder Park, where there is a shallow basin holding 200 to 300 feet of Spearfish red beds.

### VALE AND NEWELL REGION.

The artesian area of the Belle Fourche district extends for several miles down the valley and some distance up the larger branch valleys in the Vale and Newell region. An artesian well was sunk at Vale in 1909 and still furnishes a flow of good water. Its depth is 2,215 feet and it flows somewhat less than 1 gallon a minute. According to one statement shale was penetrated for 2,100 feet, at which depth some sandstone was found. This was underlain by a thin coaly layer, 25 feet of hard gray shale, and about 15 feet of white chalky clay, alternating with blue and red chalky material. At 2,200 feet sandstone was entered and at the bottom the boring was in fine black sand, which yielded the flow. The identity of the first sandstone is not clear; presumably the top of the Dakota sandstone was reached at a depth of 2,200 feet. The good quality of the water and the light flow also indicate a source near the top of this sandstone. Doubtless if the boring had been continued into the Lakota sandstone, 150 feet or more below, a large volume of water would have been obtained and under greater head. It might, however, contain more mineral matter, like the water in most wells in the Belle Fourche region and at Fruitdale. It is reported that the well is cased with 4½-inch casing at the top, 900 feet of 3-inch casing, and 1¼-inch casing at the bottom. The pressure is stated to be 22 pounds to the square inch, sufficient to lift the water 50 feet above the surface in a pipe, or to 2,824 feet above sea level.

The area in which flowing wells may be expected in the Vale-Newell area and southeastward is shown on the map (Pl. I, in pocket), as indicated by the pressures reported in wells in regions to the west and southwest and by the slope of the head toward wells in the central part of the State. Owing to the great distance between these sources of data the head can only be approximated and the boundaries of the area in which flowing wells may be obtained can be only approximately delineated. Those indicated are based on the probable head of water from the basal beds of Lakota sandstone, which has considerably greater pressure, and accordingly affords flows at higher altitudes than the water from the Dakota sandstone, or "first flow." The low pressure in the artesian well at Vale is believed to be that of the first flow, and the pressure of lower flows at that place doubtless will be found to be considerably greater, probably representing a head of more than 2,900 feet, as shown on the map. The head undoubtedly diminishes toward the east and northeast; at the mouth of Willow and Horse creeks it is probably less than 2,850 feet and may be only 2,800 feet, but this is sufficient to afford flows in all the lower lands. Flowing wells are to be expected from the second flow some distance up the slopes about Newell and in all of the lower lands about Vale, Empire, Horse Creek, Reed, and Volunteer post offices. It is likely that a flow may be obtained at Newell, altitude 2,850 feet, for the head of the second flow at that place probably will suffice to raise the water to 2,875 feet. Possibly, however, the head will be slightly less than 2,850 feet, in which event the water would come near enough to the surface to be pumped. The depth to the Dakota sandstone, or first flow, at Newell is about 2,450 feet, and the Lakota sandstone, which carries the second flow, is 150 to 200 feet deeper.

The higher ridges of the divides in the region about Newell and Vale and south and southeast of those places, as indicated on the map (Pl. I, in pocket), are probably too elevated for flows, but the limits of flow areas on these slopes can only be approximated. Apparently the prospects for flow also are fairly good in a wide area in Fourmile and Elk Creek basins, north and northeast of Volunteer.

The Minnelusa sandstone, which probably contains a large volume of water under high pressure, underlies the Vale-Newell region at depths of 3,500 to 4,000 feet, too deep for ordinary well drilling.

## STURGIS AND BEAR BUTTE REGION.

*List of wells.*—Artesian waters from the Dakota and Lakota sandstones have been developed at places north of Sturgis, and some unsuccessful attempts have been made to test lower water-bearing sandstones. The following is a list of borings within 7 miles of Sturgis:

*Deep wells in the Sturgis region.*

| Locality. | Depth. | Depth to main artesian horizon. | Diameter. | Natural flow reported. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gals. per min.* | |
| N. P. Hanson, NE. ¼ SW. ¼ sec. 15, T. 6 N., R. 5 E. | 1,116 | 1,090 | 2 | 35 | Pressure 30 pounds; some leakage. Soft water. |
| R. Stephens, NE. ¼ sec. 22, T. 6 N., R. 5 E. | 337 | 357 | 2 | 60 | Pressure 18 pounds; soft water; temperature, 44° F. |
| Eklund (old "oil well"), SE. ¼ SE. ¼ sec. 8, T. 6 N., R. 5 E. | 755 | 600 | 6–3¾ | 60 | Irony water; pressure low. |
| K. F. Kaubisch, NE. ¼ SW. ¼ sec. 20, T. 6 N., R. 5 E. | 720 | 300–400 | 2 | Few. | No water below 400 feet; water rises within 7 feet of surface; soft but irony. |
| J. S. Jensen, NW. ¼ SE. ¼ sec. 8, T. 6 N., R. 5 E. | 632 | 600 | 4½–2 | 30 | Pressure 20 pounds; soft water, some iron. |
| J. Dacy, NE. ¼ SE. ¼ sec. 12, T. 6 N., R. 4 E. | 570 | 570 | .......... | Many. | First flow at 330 feet. |
| W. H. Bowman, southwest corner sec. 2, T. 6 N., R. 5 E. | 1,560 | 1,560 | .......... | 4 | Irony water; low pressure. |
| Fort Meade | 1,450 | 322 | .......... | 12 | No water below good flow at 322 feet. |
| Sturgis, Furth Hotel | 1,050 | .......... | .......... | .......... | Failure. |
| Enskert: | | | | | |
| Lot 2, sec. 26, T. 6 N., R. 5 E. | 1,310 | .......... | 2–1½ | Few. | 45 feet above Spring Creek. |
| Lot 1, sec. 26, T. 6 N., R. 5 E. | 480 | 400 | 2 | ¾ | |

*Sturgis.*—The principal wells which tap the Lakota and Dakota sandstones are in the region north and northwest of Sturgis not far east of the foot of the hogback ridge. Here the Dakota sandstone lies less than 1,000 feet deep under a region of considerable extent, but the easterly dip carries it deeper to the east. The Lakota sandstone, which contains the principal water supplies, lies 100 to 200 feet deeper. The large igneous mass of Bear Butte locally interrupts the continuity of the water-bearing sandstones. These sandstones have been penetrated by several wells, most of which yield large flows of excellent water. One well sunk for oil at the Eklund ranch, 6 miles northwest of Sturgis, in the southeastern part of sec. 8, T. 6 N., R. 5 E., is 755 feet deep, but obtains its principal water supply at a depth of 600 feet in a bed of soft sandstone (Lakota) 85 feet thick. The flow is estimated at 60 gallons a minute, and the pressure was reported to be 20 pounds to the square inch, but a test in 1910 showed a very low figure, 5 pounds or less. A small flow was also found in the Dakota sandstone at a depth of 440 feet. The following record is given:

*Record of artesian well 6 miles north by west of Sturgis, S. Dak.*

| | Feet. |
|---|---|
| Dark shale (Graneros) | 0–275 |
| Shale and sandstone, small flow at 440 feet (Graneros and Dakota) | 275–445 |
| Red clay (Fuson) | 445–505 |
| "Rocks" (probably Lakota sandstone in part) | 505–585 |
| Soft sandstone, with main flow at 600 feet | 585–670 |
| Coal, 1 inch at | 670 |
| Dry sand | 670–685 |
| Black shale, with 2 inches of coal (basal Lakota) | 685–705 |
| Green shale, with thin limestone layers (Morrison) | 705–755 |

The Lakota sandstone appears to begin at 505 feet in this boring and to continue to the top of the Morrison shale at 705 feet, including the coaly shale at base, as in the Aladdin and Cambria areas. The Jansen well, about one-third of a mile northwest, has a 30-gallon flow from the same depth, 600 feet, and is used for irrigating several acres of orchard and garden. It is reported to have passed through 40 feet of surface material, 250 feet of shale, 10 feet of sandstone, 240 feet of hard shale, and 92 feet of sandstone—a total of 632 feet.

Another deep well (on the Kaubisch ranch), in sec. 20 of the sandstone passes beneath the Graneros shale, is 720 feet deep, but obtains its main supply from beds between 300 and 400 feet. The water rises within 7 feet of the surface, but by digging a trench it has been made to flow to the adjoining lower ground in small volume. The water is soft but contains considerable iron. The first sandstone at a depth of about 200 feet yielded water which overflowed, and the next sandstone at 400 feet yielded additional volume. At the bottom the boring was in Sundance beds containing *Belemnites*. The Dacey well, 2 miles west of the Eklund well, is 570 feet deep and obtained two flows, the first at 330 feet and the second at the bottom of the boring. The volume is large and the pressure 15 pounds to the square inch.

The Bowman well, in the southwest corner of sec. 2, T. 6 N., R. 5 E., was sunk in 1907 to a depth of 1,560 feet and flows 4 gallons a minute with low pressure. Very little information is available as to the record or other features of this well. Samples from 1,000 to 1,200 feet were all light-gray clay, apparently from the Sundance formation. Doubtless the Dakota sandstone was entered at a depth of about 700 feet and the Lakota sandstone at 850 feet, but presumably the water which they contained did not have sufficient head to afford a flow on the high table-land on which the well is situated. Probably the flow is from the basal sandstone of the Sundance formation. This well apparently shows that the altitude of head of the Dakota-Lakota water in this area is somewhat less than 3,200 feet, the height of the land on which the well is sunk. However, flowing wells may be expected throughout the lower lands to the north.

In the Hansen well, 5 miles due north of Sturgis, a depth of 1,116 feet was attained. Sandstone began at 700 feet, but no flow was obtained until the boring reached a depth of 1,090 feet, doubtless in the lower part of the Lakota sandstone. The pressure at the mouth of the well was reported to be 30 pounds, indicating a head of 69 feet, equivalent to an altitude of 3,220 feet, or somewhat higher than the altitude of outcrops of Dakota sandstone a mile to the east.

The Stephens well, a mile southeast of the Hansen well, or 4 miles north-northeast of Sturgis, is 377 feet deep. The first 250 feet consists of blue shale (Graneros), which is underlain by 25 feet of sandstone (Dakota), followed by 80 feet of gray shale (Fuson) and 22 feet of sandstone (Lakota), containing water. The pressure was 18 pounds on a pipe 10 feet lower than the well, with some slight loss by leakage. The water is said to rise 48 feet at the well, which indicates a pressure of nearly 21 pounds and a head sufficient to rise to an altitude of 3,250 feet.

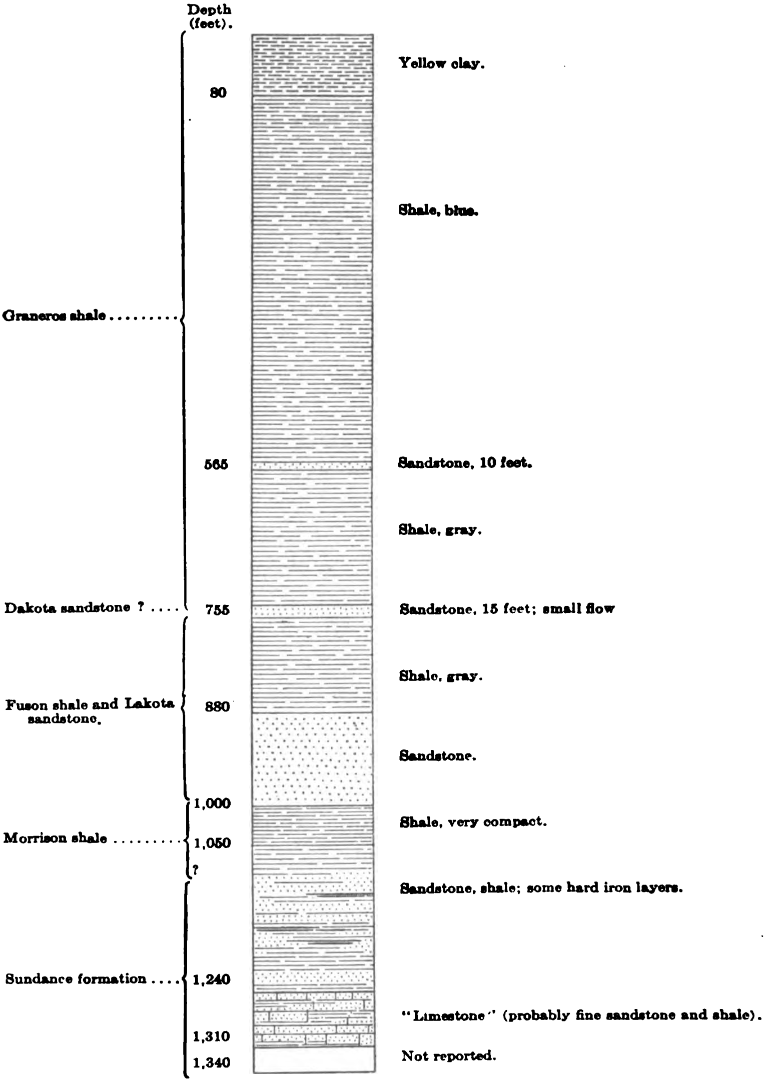


FIGURE 7.—Section of boring at Enskert ranch, lot 2, sec. 26, T. 6 N., R. 5 E., 3 miles northeast of Sturgis, S. Dak.

A 1,340-foot boring on the Enskert ranch, 3 miles northeast of Sturgis, penetrated Dakota and Lakota sandstones and nearly reached the bottom of the Sundance formation, where, on account of its small bore (2 inches), drilling had to cease. It obtained a 1 to 2 gallon flow of very hard water from sandstone, presumably Dakota, at a depth of 740 to 755 feet. The section shown in figure 7 was supplied by the driller.

A well completed in 1912 on the next lot east is 480 feet deep, a depth beyond which drilling could not proceed on account of caving of soft material. A three-fourths gallon flow of irony water (slightly alkaline) was obtained from 400 to 450 feet. Sandstone (Dakota) was entered at 345 feet. Below 450 feet were found 12 feet of white shale and 20 feet of red shale. As this well is some distance northeast of the deep one in lot 2, the shales are deeper.

It is difficult to understand why these borings did not have better success, but apparently the Lakota sandstone is choked with fine sediment at this place. If this explanation is correct, it indicates a most unusual condition, which is probably local.

*Fort Meade.*—Several years ago a well sunk by the Quartermaster's Department, United States Army, at Fort Meade, just east of the ridge of Dakota sandstone, developed a 12-gallon flow of good water at a depth of 322 feet. With the expectation of finding an additional supply it was continued deeper and penetrated the red shale of the Spearfish formation to the Minnekahta limestone, where, unfortunately, it was discontinued without testing the prospects for obtaining water in the Minnelusa sandstone 100 feet or more below. The record, based mainly on samples furnished by the quartermaster, is given in figure 8.

The boring at the Furth Hotel in Sturgis is reported to have reached a depth of 1,050 feet, where the tools stuck and work was abandoned without obtaining any water. As the boring began some distance below the top of the Spearfish formation, it should have passed through nearly all, if not all, of the Minnelusa sandstone at the depth reported and obtained a flow of water. It is stated that at about 200 feet a crevice was entered and "nothing came out of the hole" below that depth. This statement probably indicates some misunderstanding as to the depth, for the existence of such a crevice is impossible, and progress from 200 to 1,050 feet could not have been made without producing borings. It is therefore believed that the Minnelusa sandstone was not penetrated and the boring did not test the water conditions.

The wells in T. 6 N., R. 6 E., a few miles north of Sturgis, show that flowing water may be expected from the Dakota and Lakota sandstones, especially the Lakota, in a wide area of the valley lands north and east of Sturgis. Bear Butte causes a local interruption in the regular uniform dip to the eastward and deflects the "head" lines somewhat, but the general relations in most of the area are those shown in section 3 on Plate X (p. 26). In the valley of Bear Butte Creek, for example, the top of the Dakota sandstone reaches a depth of about 1,500 feet due south of the east end of Bear Butte

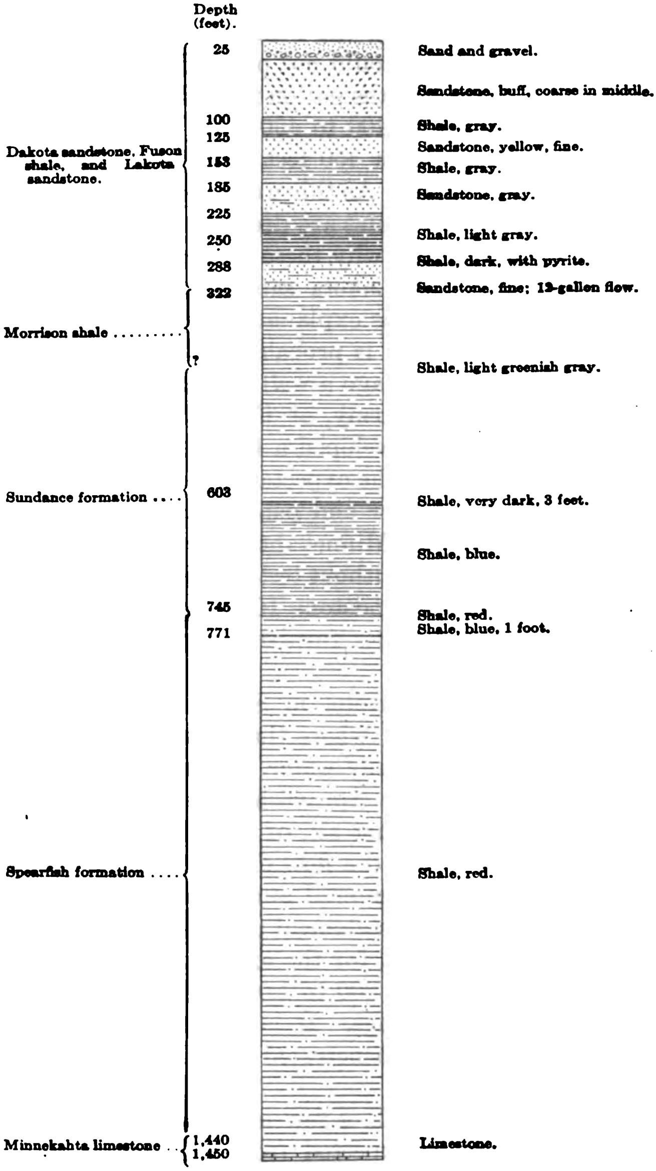


FIGURE 8.—Section of boring at Fort Meade, east of Sturgis, S. Dak.

and of 2,000 feet in the east line of R. 6 E. The flow area from Fort Meade eastward for a few miles is restricted to the bottom and lower slopes of the valley. In R. 7 E. the eastward dip of the beds diminishes in rate and probably the flow area widens greatly, especially over the low table-land south of the Bear Butte Valley. At Volunteer the Dakota sandstone is about 2,400 feet below the surface, and at Alkali and Hereford about 2,700 feet. In this region the area of flow is a wide belt adjoining the Belle Fourche Valley. (See Pl. I, in pocket.) Its limits, however, are not very accurately determined, for the probable head of the artesian water can only be approximated.

Notwithstanding the failure of the boring at the Furth Hotel in Sturgis, it is believed that the Minnelusa sandstone will yield artesian water in the Sturgis region and far up and down the Red Valley north and south, but possibly it will be necessary to sink to its lower part. The depths are indicated on the map and also in section 3 in Plate X (p. 26). About 1,100 feet deeper is the top sandstone of the Deadwood, and about 1,400 feet deeper is the basal sandstone, in which there are excellent prospects for artesian flows.

### SPEARFISH REGION.

A few borings in and near Spearfish have demonstrated the water-bearing capabilities of the Minnelusa sandstone on the northern slope of the Black Hills. They indicate that flows may be expected from this source at moderate depth in a wide area of the Red Valley extending north to Redwater Creek and eastward down the Centennial Prairie. The area over which the depth is less than 500 feet is shown on the map (Pl. I, in pocket).

*Wells in vicinity of Spearfish, S. Dak.*

| Location with reference to Spearfish. | Depth. | Depth to principal artesian horizon. | Diameter of well. | Natural flow reported. | Remarks. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Inches.* | *Gals. per min.* | |
| Normal school, 1 mile northwest. | 411 | 300 | 6¼ | 160 | Pressure 20 pounds or more. |
| ½ mile southeast | 275 | 215 | 6½ | 312 | Pressure 3½ pounds. |
| Fair grounds, ¾ mile northwest | 300 | 260 | 5 | 115 | Pressure 15 pounds. |
| Electric plant, 1½ miles south | 415 | 323-398 | .......... | 50 | Flows. |
| ¾ mile northeast | 701 | 660 | .......... | Few. | Some water within 150 feet of surface. |
| 2½ miles northwest | 312 | 305 | .......... | 15 | Pressure 20 pounds. |
| Sommers ranch, 3½ miles north | 370 | 370 | .......... | 15 | Flows. |

The water is soft and ample in volume for ranch use. The first well sunk was 415 feet deep at the electric-light plant in Spearfish Canyon, 1½ miles south of Spearfish. This well begins near the top of the Minnelusa sandstone and penetrates about 17 feet into the underlying Pahasapa limestone. A 32-gallon flow, found at a depth of 323 feet in yellow sandstone, increased to 50 gallons as the remaining 75 feet of the lower Minnelusa sandstone was penetrated. The flowing well at the fair grounds, a short distance northwest of Spearfish, is 300 feet deep, but draws its principal supply from a depth of 260 feet, probably from a top member of the Minnelusa sandstone. The pressure is 15 pounds, and the flow is 115 gallons. A similar well at the normal school is 411 feet deep and has a 160-gallon flow from a depth of 300 feet and a pressure of 20 pounds or more. A well in the NE. ¼ NW. ¼ sec. 4, T. 6 N., R. 2 E., 2½ miles northwest of Spearfish, is 312 feet deep, and its flow is under sufficient pressure to rise 45 feet above the surface. The bed that is the principal source of water lies at a depth of 305 feet. The water is medium soft and flows 15 gallons a minute. Red beds are reported to a depth of 203 feet, below which lies 2 feet of limestone, underlain by a foot of water-bearing sand. Probably the water comes up through crevices from Minnelusa sandstone far below, but may possibly come from a sandstone bed in the Sundance formation. The Harriman boring, three-fourths mile east of Spearfish, reached a depth of 701 feet. It began in the upper part of the Spearfish formation and is reported to have penetrated limestone (Minnekahta) from 453 to 483 feet. The characteristic purple clay at the top of the Opeche formation was reported at 483 to 586 feet. The record is somewhat indefinite as to underlying beds; but water which rises within 150 feet of the surface was found at a depth of 660 feet, presumably in the upper part of the Minnelusa sandstone.

A well at the Sommers ranch, 3½ miles northwest of Spearfish, is 370 feet deep and has a 15-gallon flow. It begins just above the top of the Minnekahta limestone and at a depth of 50 feet passes into Opeche shale. The water is from the lower part of the upper member of the Minnelusa sandstone.

Undoubtedly the head of water in the Minnelusa sandstone is sufficient to give flows throughout the Red Valley, except in the higher slopes and ridges. Apparently in places there is some leakage into overlying beds. Artesian water may also be expected in Deadwood sandstone in two beds, one about 1,100 feet below the top of the Minnelusa sandstone and a lower one 250 feet deeper. The lower bed has the best prospects for water, which would have a head sufficient to afford flows under high pressure in all parts of the Red Valley, except, perhaps, the highest parts of the adjoining slopes or the ridge culminating in Lookout Peak.

### RAPID CITY REGION AND EASTWARD.

Three flowing wells in the Red Valley, 2 miles northwest of Rapid City, indicate that water is obtainable from the Minnelusa sandstone in that district. The first well, which is at the lime plant in the SE. ¼ sec. 28, T. 2 N., R. 7 E., begins on top of the Minnekahta limestone and is 250 feet deep, reaching the middle of the upper sandstone of the Minnelusa. The main flow of 100 gallons a minute began at a depth of 215 feet and did not increase below that point. Another well in the northeast quarter of the next section south obtains a similar supply from the same source at a depth of 205 feet. The third well is in the SW. ¼ sec. 34, nearly a mile southeast of the second. It is 500 feet deep and flows about 60 gallons. It was necessary to go 500 feet at this place to reach the same stratum as in the other wells, for the beds pitch steeply to the southeast, as shown by an outlier of the Sundance formation at the road forks, less than half a mile southeast.

A few borings of moderate depth have been made east of Rapid City, but none sufficiently deep to reach the Dakota sandstone. Owing to the relatively steep dip of the rocks, the depth to this sandstone increases rapidly east of the hogback ridge. In the eastern part of Rapid City the depth is 500 feet, and along the eastern margin of R. 8 E. it is probably considerably more than 2,500 feet. Doubtless flowing wells could be obtained at depths of 500 to 1,500 feet along the valley of Rapid Creek west of the center of R. 8 E., and at a depth of 1,500 feet in the wide flats west of Box Elder Creek, 2 miles northeast of Rapid City. At Brennan the sandstone probably lies at a depth of about 1,300 feet, but whether it would yield a flow is somewhat doubtful, for the limit of the area in which flows may be expected is in the vicinity of the railroad at Brennan.

A boring made at Wasta, a few miles east of the border of the area shown on the map (Pl. I, in pocket), is 2,287 feet deep. At 2,208 feet a 3-foot bed of sandstone was penetrated and yields water that rises within 300 feet of the surface, here 2,315 feet above sea level. The supply is 40 gallons a minute, and is obtained with a 4-inch pump barrel at a depth of 900 feet. The sandstone evidently is included in either the Carlile or Graneros shale, probably the Graneros; and if so the Dakota sandstone is not far below.

### HERMOSA REGION.

In the valleys of Spring and Battle creeks conditions are similar to those in the Rapid City region. Probably flowing wells can be obtained in all the bottom lands and lower slopes of the larger valleys. The area in which flows of water from the Dakota and Lakota sandstones may be obtained is somewhat uncertain, for the boundaries shown on the map (Pl. I, in pocket) are constructed from head lines that are only approximately located. It is probable that

Hermosa station is near the edge of the area and that a flow might be obtained there from the Dakota or Lakota sandstones. The Dakota is probably not more than 700 feet below the surface. The Lakota lies 850 feet below, and from it the greatest head and largest flow are to be expected. On the east line of R. 8 E. the depth to the Dakota sandstone is between 1.600 and 1,700 feet on Battle Creek and also on Spring Creek. It gradually deepens to the east, probably to 2,600 feet on the east line of R. 9 E.

In the Red Valley west of Hermosa the Minnelusa sandstone is within reach for ordinary well boring and is likely to yield a flow in the lower and middle slopes. The depth is 150 feet to the top sandstone at the foot of the limestone slopes and 750 to 800 feet along the eastern edge of the red beds of the Spearfish formation. At Hermosa it is about 2,200 feet below the surface, and the top or lower sandstones are likely to afford a flow under considerable pressure. The Deadwood sandstone is about 1,000 feet below the top of the Minnelusa sandstone in this region.

### FAIRBURN REGION.

The artesian conditions in the Fairburn region (see Pl. I, in pocket, and section 5, Pl. X, p. 26) are similar to those all along the east slope of the Black Hills. No wells have been sunk, and the water resources are therefore untested, but there is every probability that water is obtainable. Flows may be expected along the valleys of Dry Creek and French Creek, from the foot of the hogback ridge eastward, with gradual increase in depth and diminution of head. At Fairburn the head of the first flow is probably sufficient to raise the water to about 3,300 feet above sea level (Fairburn station is 3,310 feet), or sufficiently high to afford a flow in the lower lands near by. Somewhat greater head may be expected from lower flows. The depth to the top of the Dakota sandstone is 900 to 1,000 feet at Fairburn. It increases steadily to the east, and in the northeast corner of T. 5 S., R. 8 E., it is 2,500 feet, east of which it increases but slightly, for the strata lie nearly horizontal.

At Fairburn the Minnelusa sandstone is about 2,500 feet below the surface and the Deadwood sandstone 800 to 900 feet deeper, but in the Red Valley the depth to the Minnelusa is only 140 to 1,200 feet, and to the Deadwood sandstone 1,000 to 2,000 feet. Both probably contain artesian water under considerable pressure.

### BUFFALO GAP AND SMITHWICK REGION.

Several deep borings have been made in and near the town of Buffalo Gap, but none of them was sufficiently deep to be successful. One was on a hill just west of the town. Another, on the principal street, was 800 feet deep, entirely in black shale. It began in the lower part of the Carlile shale, above the Greenhorn limestone, and passed far down into the Graneros shale. Probably the Dakota sandstone would have been entered at a depth of about 1,100 feet and a flow obtained.

The most recent attempt to obtain water was by a deep well a mile west of town, which was drilled in 1910, but it was located too high to have a flow. The depth was 884 feet. No record was obtainable as the well was sunk by jetting, but it is reported that the base of the shale was between 500 and 600 feet. The well was cased with 4½ to 2 inch pipes and the 2-inch pipe was perforated from 654 to 784 feet. Water that could be pumped was obtained at 654 to 784 feet, and though at first it came to the top it settled back to 725 feet. However, after two years this afforded a small flow which has continued since.

All the conditions appear to be favorable for obtaining flows in all of the lower lands of the valleys of Lame Johnny, Dry, and Beaver creeks and Cheyenne River, north, south, and east of Buffalo Gap. (See map, Pl. I, in pocket.) Owing to the relatively steep dips of the rocks near the hogback ridge the depths to the water-bearing sandstones increase rapidly to the east for some distance. At Buffalo Gap station the depth is about 1,300 feet, and in the next 2 or 3 miles it increases to 2,300 feet. The dips flatten in R. 8 E. (see section 6, Pl. X, p. 26), and the strata rise slightly in a low dome in the next two ranges east. The Dakota sandstone lies, however, at a depth of 2,300 to 2,600 feet in this region. The area in which flows may be obtained undoubtedly extends up the valley of Cheyenne River past Oral to the mouth of Fall Creek and possibly also to the mouth of the gorge in which the river crosses the hogback ridge a few miles above Cheyenne Falls.

Artesian water will perhaps be found in the Minnelusa sandstone also, unless the rock becomes too fine grained, as at Edgemont and Minnekahta. It lies from 500 to 800 feet below the surface in the lower parts of Martins Valley. Probably the water in the large springs in the upper part of Buffalo Gap rises from this sandstone through the Opeche beds, and if so, there is much encouragement for believing that the sheet of water may be widespread. About 1,100 feet below the surface is the Deadwood sandstone, which undoubtedly carries a large water supply, as in deep wells at Edgemont.

## HOT SPRINGS AND MINNEKAHTA REGION.

The town of Hot Springs extends nearly all the way across the Red Valley and is underlain by the Minnelusa sandstone at depths ranging from about 200 feet in the western part of the town to 800 feet or more in the eastern part of the "old town." It is likely that this sandstone contains water throughout the Red Valley and that additional supplies are obtainable in the Deadwood sandstone about 1,000 feet below. Probably the warm water of the noted springs above Hot Springs is from this source and thus rises 1,000 feet or more through crevices in overlying rocks. Otherwise it is difficult to account for their temperature, which is about 45° higher than the mean annual temperature of the locality. The water of the tepid springs at Cascade doubtless comes from the same horizon. At the Soldiers' Home, a short distance west of Hot Springs, a well, sunk several years ago to a depth of 223 feet, begins just above the top of the

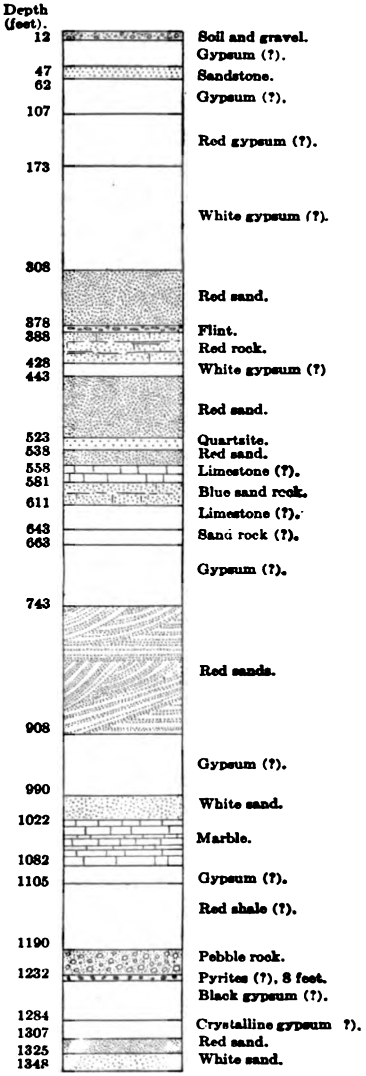


Figure 9.—Section of deep boring at Minnekahta, S. Dak.

Minnekahta limestone and obtains a moderate water supply from the Minnelusa sandstone.

Several years ago the Chicago, Burlington & Quincy Railroad Co. made a deep boring at Minnekahta station to obtain a water supply for locomotives. A depth of 1,348 feet is said to have been attained, but no satisfactory amount of water was found. The section shown in figure 9 is clearly unreliable and very unsatisfactory for the identification of the rocks penetrated. The reference to gypsum, except those near the top, are mistakes as to the identity of the material. No clue is given as to the position of the Minnekahta limestone, which lies about 500 feet below the surface. The red sands from 743 to 908 feet are doubtless part of the Minnelusa sandstone. At a depth of 1,348 feet the boring should be in or near the Deadwood sandstone, for the thickness of the beds from the upper part of the Spearfish red shale, in which the boring was started, to the top of the Deadwood sandstone is not much more than this in the surface exposures in the region to the north. Possibly the red sand reported from 1,307 to 1,325 feet is from the top of the Deadwood sandstone, and if so the boring would have found the water-bearing strata of the deep Edgemont wells at no great depth below. As the Minnekahta station is at an altitude of 4,163 feet, and as the altitude of intake of the Deadwood sandstone near Pringle is at about 5,000 feet, it is probable that the water would flow throughout this portion of the Red Valley.

### EDGEMONT REGION.

*Edgemont.*—Two deep artesian wells afford a large water supply for Edgemont. One, in the northern edge of the town, sunk by the Chicago, Burlington & Quincy Railroad in 1905, reached a depth of 2,980 feet in 1907, and the other, sunk by the city in 1912 a few rods south of the depot, is 2,983 feet deep. They both yield large flows of warm water (122° and 126° F.) under pressure of about 75 pounds to the square inch, probably derived from Deadwood sandstone. (See section 6, Pl. X, p. 26.) Several shallower wells penetrate the Dakota and underlying sandstones, but the head of the water in these beds is too low to afford a flow. The flow in the deep railroad well began at 2,920 feet and finally it was 300 gallons a minute as boring progressed. At first the water contained much mineral matter, evidently derived from red sandstone in higher beds, for the boring was not cased between 1,850 and 2,111 feet, but a 5-inch casing inserted to the latter depth cut off this water and the main supply was then found to be satisfactory for locomotives. (See analysis, p. 57.) The following is the record furnished by the company, with slight modifications based on examination of samples sent by the drillers and others:

*Record of artesian well of Chicago, Burlington & Quincy Railroad Co. at Edgemont, S. Dak.*

| | Feet. |
|---|---|
| Clay and sand, with gravel at base | 0– 33 |
| Shale, dark | 33– 90 |
| Sandstone | 90– 98 |
| Shale, with 3-inch bed of hard sandstone at 297 feet | 98– 343 |
| "Limestones" separated by 2 feet and 9 feet of light-colored shales (probably top of Dakota) | 343– 375 |
| Shale, dark, compact | 375– 377 |
| Sandstone, hard, with 6 feet of dark shale near top | 377– 407 |
| Pyrites (?) | 407– 409 |
| Shale, gray, with 2-foot hard layer | 409– 420 |
| Sandstone, with dark shale near base | 420– 440 |
| Shale, mostly light and soft | 440– 462 |
| Sandstone ("limestone" in middle; 4 feet hard shale at 489 feet) | 462– 503 |
| Shale, compact, light | 503– 524 |
| Sandstone, hard, and sandy "limestone" | 524– 559 |
| Shale, sandy | 559– 618 |
| Sandstone, red | 618– 644 |
| Shale, sandy, compact | 644– 669 |
| Sandstone, with water | 669– 672 |
| Shale, sandy, compact, with 24 feet of "limestone" at 740 feet | 672– 774 |
| Sandstone, light-colored (Unkpapa) | 774– 841 |
| Sandy shale, compact (probably top of Sundance) | 841– 855 |
| Shale, blue | 855– 955 |
| Sandstone | 955– 965 |
| Shale, red, sandy (probably red member of Sundance formation) | 965–1,040 |
| Sandstone, dark red, compact (probably red member of Sundance formation) | 1,040–1,051 |
| Shale, white, sandy | 1,051–1,060 |
| Shale, blue | 1,060–1,080 |
| Sandstone, white; water rose to surface | 1,080–1,098 |
| Shale, blue | 1,098–1,157 |
| "Hardpan," black | 1,157–1,174 |
| Sandstone, white, some water (low in Sundance) | 1,174–1,223 |
| Shale, gray, limy (reported as black hardpan; probably at base of Sundance) | 1,223–1,230 |
| Red shale and sandstone (Spearfish) | 1,230–1,850 |
| Red sandstone (Minnekahta limestone, not reported) | 1,850–1,955 |
| Limestone, light colored (probably fine Minnelusa sandstone) | 1,955–2,140 |
| Limestone, pale brown (probably fine Minnelusa sandstone) | 2,140–2,198 |
| Red sandstone (5 feet compact at top, then very soft for 24 feet) | 2,198–2,292 |
| Limestone | 2,292–2,303 |
| Sandstone, red and gray | 2,303–2,325 |
| Limestone, white | 2,325–2,352 |
| Sandstone, some lime (reported as limestone) | 2,352–2,440 |
| Limestone, white (Pahasapa) | 2,440–2,516 |
| Sandstone, red; dark brown below | 2,516–2,572 |

| | Feet. |
|---|---|
| Sandstone, light brown; no lime | 2,572–2,641 |
| Pyrites, dark | 2,641–2,648 |
| Red rock, soft above, light in middle, darker below | 2,648–2,878 |
| Sandstone, first flow between 2,920 and 2,948 feet | 2,878–2,890 |
| Red sandstone, very hard 6-inch layer at 2,964 feet | 2,890–2,980 |

The identity of some of the rocks given in this record is questionable, especially the so-called limestones, and the limits of the different beds are by no means accurate. Apparently the Dakota sandstone was reached at a depth of 297 feet, and presumably the base of the Lakota sandstone is the water-bearing sand from 669 to 672 feet. The Morrison, Unkpapa, and Sundance formations lie next below, with the sandstone in the lower part of the Sundance extending from 1,174 to 1,223 feet. The Spearfish began at 1,230 feet (according to another authority, at 1,255 feet, capped by 15 feet of coarse gray sand), and red beds continued with great uniformity to 1,955 feet, presenting a thickness of more than 700 feet. It is probable, however, that the Minnekahta limestone was penetrated at about 1,850 feet, and the Opeche red sandstone is included in the 700 feet of red beds. Possibly, also, some of the top sandstone of the Minnelusa is included on account of its red color. The identity of the lower beds is difficult to establish. Many feet of the sandstones and limestones are Minnelusa. The base of the Pahasapa (and Englewood) limestones appears to be at the bottom of the thick body of limestone at a depth of 2,516 feet. The beds below this limestone to 2,920 feet are mostly sandstones and shales, largely red, but some of the sandstones are snuff-colored and very like the upper part of the Deadwood sandstone. No samples were obtained from the "sands" at 2,920 to 2,980 feet on account of the heavy flow of water.

An analysis of the water made for the railroad company 10 days after the well was cased is as follows:

*Analysis of water from Chicago, Burlington & Quincy Railroad Co.'s artesian well at Edgemont, S. Dak.*[a]

| | Parts per million. |
|---|---|
| Silica, iron, and alumina | 20 |
| Calcium (Ca) | 98 |
| Magnesium (Mg) | 48 |
| Sodium (Na) | 122 |
| Carbonate radicle ($CO_3$) | 174 |
| Sulphate radicle ($SO_4$) | 173 |
| Chloride radicle (Cl) | 168 |
| Total dissolved solids | 803 |
| Probable scale-forming ingredients | 390 |
| Probable foaming ingredients | 330 |

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[a] This analysis was reported by the railroad company in grains per gallon and has been recalculated into ionic form and parts per million by the United States Geological Survey. The total contents in grains per gallon were given as 45.88, of which sodium chloride was 16.19, sodium carbonate 1.69, calcium sulphate 14.29, calcium carbonate 3.85, magnesium carbonate 9.86, silica and insoluble matter 1.18.

In 1910 another deep well was sunk in Edgemont to supply water for city use. A flow of 575 gallons a minute was found at 2,970 feet. The pressure is 94 pounds to the square inch, and the temperature is 126° F. The following record was supplied by the drillers:

*Record of artesian well sunk in 1910 for city of Edgemont, S. Dak.*

|  | Thickness. | Depth. |
|---|---|---|
|  | *Feet.* | *Feet.* |
| Clay, sand, and gravel | 60 | 60 |
| Shale, mostly dark | 270 | 330 |
| Sand; water rose to 20 feet below the surface | 7 | 337 |
| Shale, gray to red, sandy near base | 86 | 423 |
| Sand | 6 | 429 |
| Shale, blue | 6 | 435 |
| Sand | 3 | 438 |
| Sandy shale, white | 8 | 446 |
| Sand | 9 | 455 |
| Shale | 5 | 460 |
| Sand, hard sharp | 15 | 475 |
| Shale, gray to white, part sandy | 55 | 530 |
| "Sharp lime" | 20 | 550 |
| Sandy shale | 23 | 573 |
| Sand, white | 17 | 590 |
| Shale, brown to white | 52 | 642 |
| "Hard lime" on 2 feet of sand | 36 | 678 |
| Shale, black, hard | 6 | 684 |
| Shale, lower half soft and white | 71 | 755 |
| "Lime" and shale | 10 | 765 |
| Red rock | 8 | 773 |
| "Limestone" | 6 | 779 |
| Sand, white | 18 | 797 |
| Shale, lower 90 feet blue | 161 | 958 |
| "Hard lime" sandy "shells" | 9 | 967 |
| Shale, white and pink | 21 | 988 |
| Red rock | 6 | 994 |
| Shale, part hard and white | 31 | 1,025 |
| Red rock, hard | 17 | 1,042 |
| Shale, white at top, blue below | 54 | 1,096 |
| Sand with water | 4 | 1,100 |
| Shale, blue to gray | 78 | 1,178 |
| Sand with 5-gallon flow | 67 | 1,245 |
| Shale, hard | 9 | 1,254 |
| Red rocks, hard to soft | 372 | 1,626 |
| Sand, light hard | 28 | 1,654 |
| Lime, white, hard | 16 | 1,670 |
| Red rocks, mostly soft, flow at 1,845 feet | 185 | 1,855 |
| Sandstone, white | 45 | 1,900 |
| Sandstone, red | 30 | 1,930 |
| Limestone, mostly white | 152 | 2,082 |
| Limestone, red, gray, and white, very sandy | 62 | 2,144 |
| Red rock; caves easily | 111 | 2,255 |
| Sand, gray | 21 | 2,276 |
| Shale, blue | 9 | 2,285 |
| "Lime" | 15 | 2,300 |
| Red rock | 25 | 2,325 |
| Sand, gray, soft below | 24 | 2,349 |
| Sand, white, soft | 31 | 2,380 |
| Limestone, hard, dark | 145 | 2,525 |
| "Sandy" and blue shale | 90 | 2,615 |
| Red rock | 20 | 2,635 |
| "Hard and sandy" and sand | 25 | 2,660 |
| "Red cave" | 25 | 2,685 |
| Sand, hard | 12 | 2,697 |
| Red rock | 28 | 2,725 |
| Limestone layer, white; has hard red streaks | 30 | 2,755 |
| Red rock | 156 | 2,911 |
| Limestone, dark, 42-gallon flow at 2,930-2,942 feet and 60-gallon flow at 2,950 feet | 39 | 2,950 |
| Main flow, 575 gallons a minute | 33 | 2,983 |

This record corroborates the previous one in most respects, certainly as to the great flow of warm water at the bottom. Owing to the slight northward dip of the strata the beds are slightly deeper in the new well than in the old one.

Apparently the Dakota sandstone was entered at 330 feet and probably the white sand at 779 to 797 feet is basal Lakota. The "red rocks," at 988 to 1,042 feet, suggest the red member in the middle of the Sundance formation, and the water-bearing sand 200 feet below is the lower sandstone of that formation. The red beds of the Spearfish formation begin at 1,254 feet, or 24 feet deeper than in the railroad well. The sand and lime reported at 1,626 to 1,670 feet are probably gypsum; and the "white sandstone," at 1,855 to 1,900 feet, may be gypsum or may be Minnekahta limestone, which is 45 feet thick at its outcrops 15 miles to the north. The overlying red beds are 601 feet thick, which is the estimated amount of the Spearfish formation in its outcrops to the north. The red beds at 1,900 feet are probably Opeche, but only 30 feet are reported. The sandstones below are the Minnelusa, which doubtless extends to 2,380 feet. According to the record the Pahasapa limestones are less characteristic than might be expected, and their lower limit is not indicated. Undoubtedly the lower sandstones are Deadwood and yield the flow. A small showing of oil was reported at 2,200 feet.

The well is cased with 34 feet of 16-inch pipe, 1,275 feet of 10-inch pipe, 2,290 feet of 8-inch pipe, and 2,912 feet of 6-inch pipe.

It is interesting to compare the Edgemont well sections, or at least the portions of them from 850 to 2,300 feet, with the record of a boring recently made for oil on Old Woman Creek 25 miles southwest of Edgemont.

*Record of boring for oil on Old Woman Creek anticline, in the NW. ¼ sec. 9, T. 36 N., R. 62 W., in Wyoming, 25 miles southwest of Edgemont, S. Dak.*

| Formation. | Material. | Thickness. | Depth. |
|---|---|---|---|
| | | *Feet.* | *Feet.* |
| Sundance | Shale, gray to blue below, reddish in upper part | 255 | 255 |
| | Sandstone, soft, white; some gas | 80 | 335 |
| | Shale, gray, hard | 20 | 355 |
| Spearfish | Red beds | 415 | 770 |
| Minnekahta | Limestone; water at base | 70 | 840 |
| Opeche | Shale, red | 80 | 920 |
| Minnelusa | Sandstone, white, granular | 100 | 1,020 |
| | Sandstone, reddish, limy, hard | 18 | 1,038 |
| | Sandstone, gray, limy, hard | 12 | 1,050 |
| | Shale, red | 10 | 1,060 |
| | Sandstone, much lime, very hard | 100 | 1,160 |
| | Limestone, gray, siliceous | 30 | 1,190 |
| | Limestone, white, siliceous | 140 | 1,230 |
| | Sandstone, brownish and white; some water | 20 | 1,250 |
| | Limestone, gray above, very dark below | 91 | 1,341 |
| | Shale, red | 9 | 1,350 |
| | Shale, dark, compact | 30 | 1,380 |
| | Sandstone, white; much lime | 20 | 1,400 |
| | Limestone, dark gray, sandy | 18 | 1,418 |
| | Sandstone, brownish | 26 | 1,444 |
| | Limestone, brownish | 12 | 1,456 |

In Edgemont and its vicinity a number of wells were sunk several years ago for water from the Dakota sandstone. Nearly all obtained supplies for pumping, but, owing to the low level of the outcrops of the Dakota sandstone in the vicinity, the water did not have sufficient head to flow. The water did not prove satisfactory for use in locomotives, and all the wells except the one 1,125 feet deep at the railroad roundhouse have been abandoned.

Sections of two wells are shown in figures 10 and 11. One of the wells at the roundhouse (fig. 10) had a depth of 1,125 feet but is now filled to the depth of 700 feet. Water of bad quality was found in the white sand at 295 feet and in the sandstone at 977 feet. Fairly good water,[1] rising within 60 feet of the surface, is obtained from the sandstone which begins at a depth of 509 feet. It contains 4,080 parts per million of solid matter (239 grains per gallon), of which 159 parts is lime. The record appears to be fairly reliable; it indicates Dakota sandstone from 295 to 350 feet, Fuson shale from

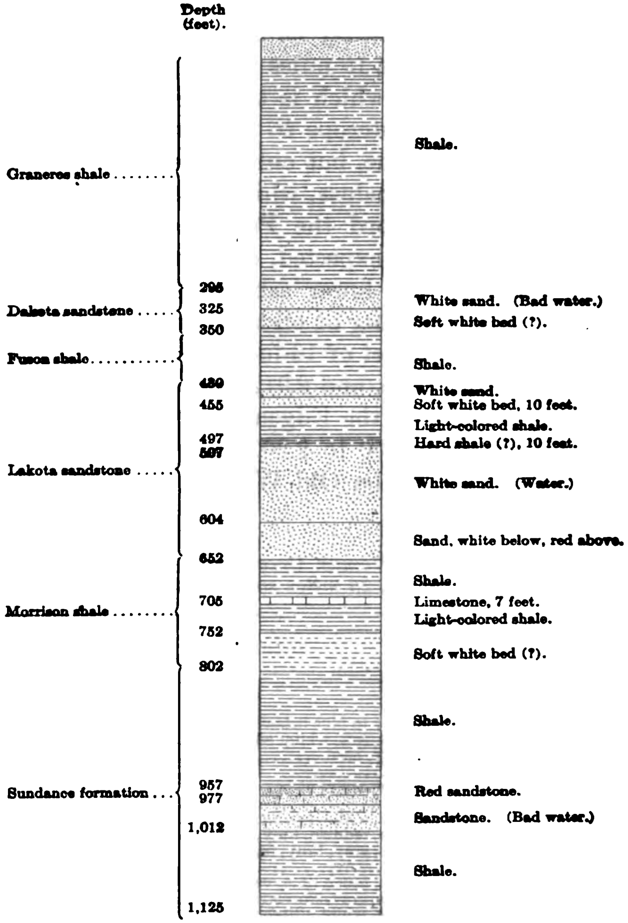

FIGURE 10.—Section of nonflowing well at Edgemont, S. Dak.

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[1] Darton, N. H., Geology and underground waters of South Dakota: U. S. Geol. Survey Water-Supply Paper 227, p. 95, 1909.

350 to 430 feet, Lakota sandstone from 430 to about 652 feet, Morrison shale from 652 to 802 feet, Sundance shales and sandstones with the characteristic red series from 957 to 977 feet, and the bed of buff sandstone 977 to 1,012 feet, with the basal dark shales thence to 1,125 feet, which is probably not more than 40 feet above the top of the red beds of the Spearfish formation.

The well at the north end of the railroad Y across the river from Edgemont (fig. 11) has a depth of 960 feet, and probably ends in shale of the Sundance formation, but the record appears not to be reliable in its details. Some water was found in the white sand at 230 feet and in sandstones at 290 and 430 feet. At 578 feet a sandstone begins which yields a good supply of water that rises within 30 feet of the surface. A thin sand rock at 703 feet also yields water, but its volume is small.

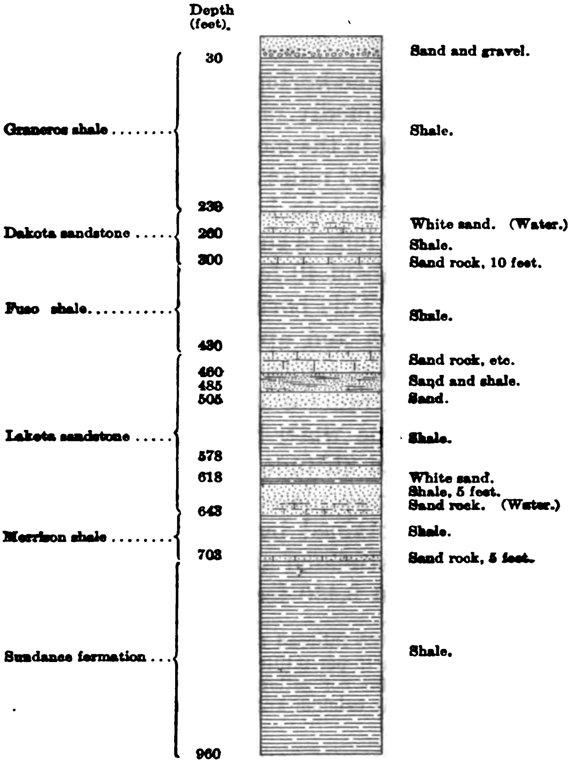

FIGURE 11.—Section of boring at railroad Y three-fourths of a mile north of Edgemont, S. Dak.

*Argentine.*—The Chicago, Burlington & Quincy Railroad Co. has a flowing well on the south bank of Pass Creek just west of Argentine, a siding 13 miles northwest of Edgemont. It is 550 feet deep and yields considerable water, but its quality is not satisfactory for locomotives, as the following analysis shows:

*Analysis of artesian water from Argentine, S. Dak.*[1]

| | Parts per million. |
|---|---|
| Silica ($SiO_2$) | 3.0 |
| Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$) | 1.0 |
| Calcium (Ca) | 62 |
| Magnesium (Mg) | 20 |
| Sodium (Na) | 220 |
| Potassium (K) | 1.0 |
| Carbonate radicle ($CO_3$) | 110 |
| Sulphate radicle ($SO_4$) | 521 |
| Organic and volatile matter | 9.0 |
| Total solids | 947 |

No record of the Argentine boring was obtained. It begins in the Graneros shale and undoubtedly obtains the flow from the Lakota sandstone, which crops out in the mountains not far east.

*Ardmore.*—At Ardmore, 23 miles south of Edgemont, the Chicago, Burlington & Quincy Railroad Co. bored to a depth of 1,500 feet without obtaining water. The hole is entirely in shale, except at the bottom, where it penetrated about 40 feet of white sand, containing thin partings of black shale. This boring begins just about at the top of the Niobrara formation and apparently penetrates very nearly to the Dakota sandstone, the sandstone bed reported probably being in the lower part of the Graneros shale. As Ardmore is at an altitude of 3,557 feet, and the water-bearing Dakota sandstone crops out about Edgemont at an altitude of 3,400 feet, there is no possibility of a flow at the former place, but probably a supply of water for pumping could be obtained by deepening the boring into the Dakota sandstone. The estimated altitude to which the water would rise in such a well is about 3,450 feet.

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[1] The analysis was reported by the railroad company in grains per gallon, and has been recalculated into ionic form in parts per million by the United States Geological Survey. The total solids are about 55 grains per gallon, regarded as about 40 grains sodium and potassium sulphates and 12 grains calcium and magnesium sulphates and carbonates.

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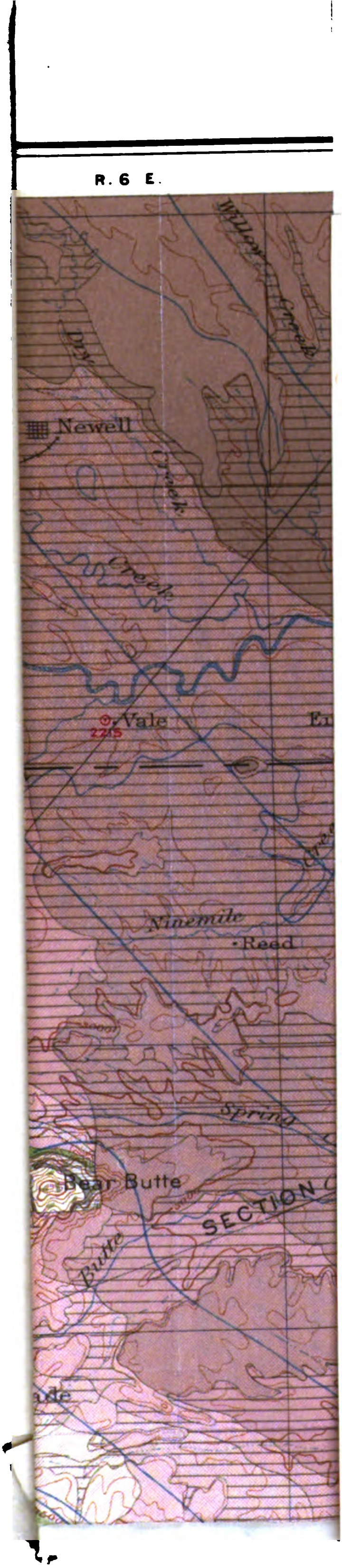
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